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FUEL STORAGE AREA GROUNDWATER QUALITY STUDIES 1979 - 1984 THUNDER BAY TGS EXTENSION

Report No 85-179-K

J. Complak and D.R. Chartier
Chemist Research Chemist
Environmental and Inorganic
Research Section
Chemical Research Department

ABSTRACT

Data on the physical and chemical characteristics of groundwaters from the fuel storage areas at Thunder Bay TGS, from 1979 through 1984, are analyzed in this report.

A statistical analysis was performed in order to ascertain whether significant changes in groundwater quality had occurred in the site as a result of coal storage. It was found that there had not been any significant changes in groundwater quality over the study period; waters which were acidic from the outset remained acidic and the nonacidic natural waters remained unchanged.

Recommendations are made to reduce the number of analytes to be determined and to perform the analyses only at TBTGS. A reassessment of the site condition is not warranted until sufficient data has been accumulated.

job	file	date	report no.
740631-136-492	837.331	January 30, 1986	85-179-K

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EXECUTIVE SUMMARY

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Data on the physical and chemical characteristics of groundwaters from the fuel storage areas at Thunder Bay TGS, from 1979 through 1984, are analyzed in this report.

A statistical analysis was performed in order to ascertain whether significant changes in groundwater quality had occurred in the site as a result of coal storage. It was found that:

- the bituminous coal pile had caused acidification of groundwater in its immediate locale but the pH levels have not changed significantly over time.
- on the basis of the available data, there is no statistically significant difference between the designated 'preoperational' and the 'postoperational' periods.
- the variations in analyte concentrations in the groundwater from nonacidic piezometers, as a function of time, reflect the natural variations which can be attributed to variations in site hydrogeochemistry.

It was recommended that some consideration should be given to reducing the number of analytes to be determined on each set of samples and to resolving the discrepancy between the results obtained at the two laboratories. This could be done by performing a reduced set of analyses only at TBTGS, on fresh water samples, before their characteristics change with time. Also, Piper diagrams should continue to be used to identify outliers in major ion chemistry. A statistical reassessment should be performed only when the data set has increased significantly in size (5 years hence would be appropriate).

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D Statistical report S. Bartlett

DISTRIBUTION

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TO: Dr. W.R. Effer
Manager
Environmental Studies and
Assessments
Design and Development Division - Generation

FUEL STORAGE AREA GROUNDWATER QUALITY STUDIES 1979 - 1984 THUNDER BAY TGS EXTENSION

INTRODUCTION

A survey of groundwater quality in the vicinities of the bituminous and lignite coal piles at Thunder Bay TGS Extension (TBTGS), was conducted during 1984. This survey is a continuation of the 'preoperational' groundwater surveys conducted by London Monenco Consultants (LMC) during 1979/1/, and by Ontario Hydro during 1980-81/2,3/ and the 'postoperational' surveys conducted by Ontario Hydro during 1982-83/4,5/. The data obtained during the 1984 survey are summarized and discussed in this report. In addition, a statistical analysis and discussion of all data from 1979 to 1984 are included.

The purpose of these surveys was to obtain baseline data on the hydrology and chemistry of the groundwater at the site prior to 1982, considered to be the 'preoperational' period, and on the water quality during the subsequent years, considered to be the 'postoperational' period. These data are required for design verification purposes and for evaluation of environmental impacts due to:

(i) the placement of a lignite coal storage pile and coal transfer activities north of the plant, and

(ii) the construction of drainage ditches along the north and east sides of the lignite coal storage area and along the south and east sides of the bituminous coal pile (see Figure 1), to collect and hold surface run-off to minimize infiltration of coal leachate to the groundwater.

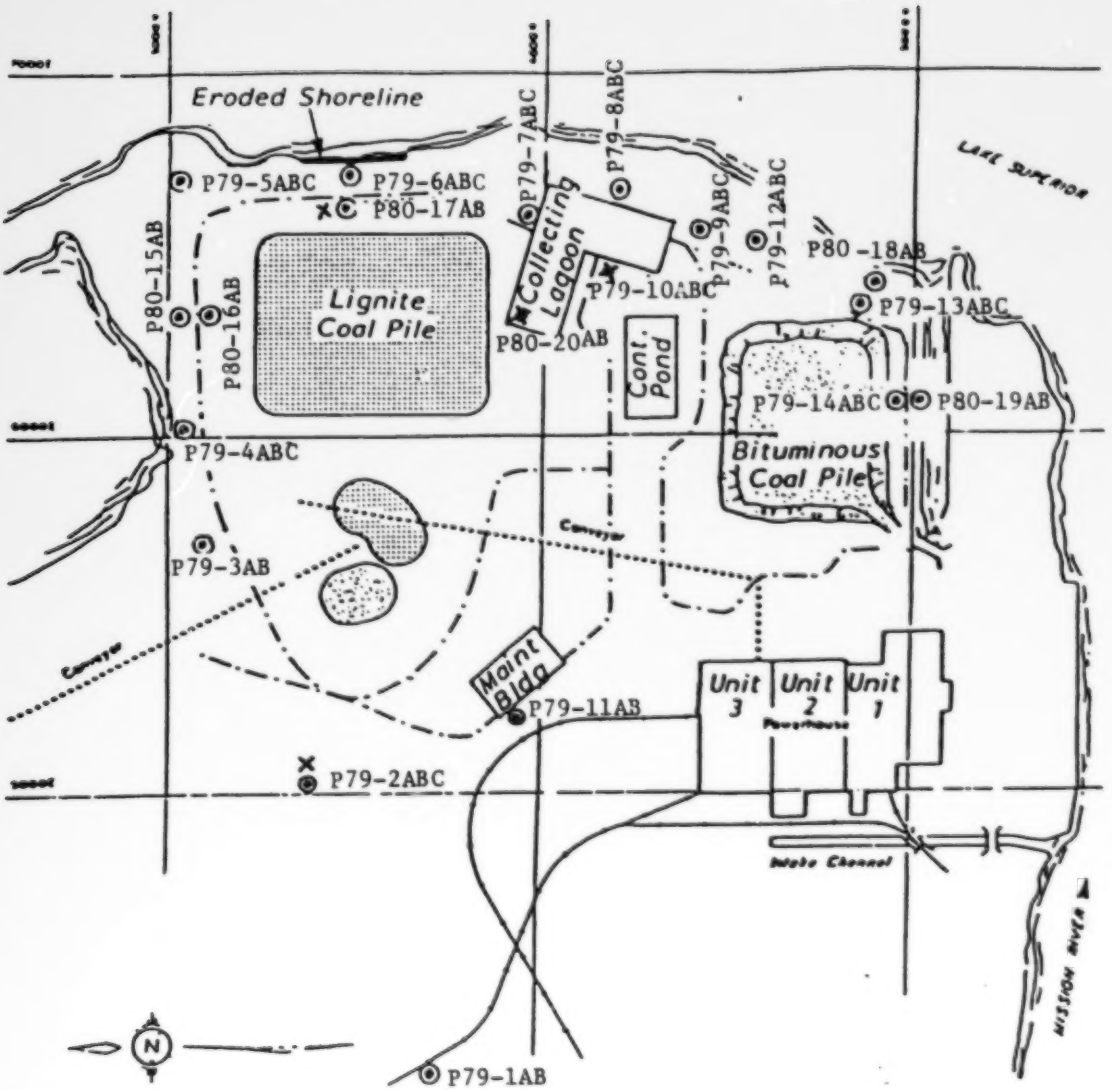

FIGURE 1

PIEZOMETER, PONDS, DITCHES, SHORE EROSION AREA AND FUEL STORAGE LOCATIONS THUNDER BAY TGS EXTENSION 1984

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The accumulated data will also serve to identify any future changes in groundwater quality and to indicate when corrective action should be taken.

These surveys were conducted at the request of Ontario Hydro's Environmental Studies and Assessments Department on behalf of the Thunder Bay Extension Project.

HISTORY OF THE FUEL STORAGE AREA - TO END OF 1984

The following is a brief outline of the main events in the history of the 'Fuel Storage Areas' shown in Figure 1.

(1) The coal pile for Unit #1 (sub-bituminous coal) had existed since the 1950's.

(2) Coal (lignite) for Units #2 and #3 had been stockpiled in the 'lignite storage area' since late 1980. New lignite was stockpiled beginning in early 1981.

(3) Ditches to intercept coal pile drainage (Figure 1) were completed in November 1981.

(4) Significant erosion of the shoreline in the vicinity of piezometer nest 6 occurred in 1983. Piezometer nest 6 is now only 1 m away from the shoreline. Piezometer nest 5 is also expected to be similarly affected.

(5) A 100 m section in the central part of the eroded shoreline was rehabilitated in October 1983, and the remaining 300 m section was rehabilitated in September 1984.

(6) The bituminous coal storage area was cleared of usable coal in mid-1984. Only about 1 200 Mg of bituminous coal remains east of the lignite pile.

METHODOLOGY

The following is an outline of the preparatory field work carried out and the test methods used to obtain the raw data needed to characterize the hydrology and the quality of the run-off and the groundwater in the coal storage areas.

1. Piezometer Installation

Initially a piezometer network, consisting of 39 piezometers at 14 sites, was installed in 1979 by London Monenco Consultants Ltd/1/. Additional 12 piezometers were installed at six sites in 1980 by Ontario Hydro. The piezometers are, for the most part, in the silty sand ground layer and were installed to monitor lower, middle and upper sections of this deposit. The depths of all piezometers are shown in Table I and the typical LMC piezometer construction details/1/ in Figure 2 and Table II.

2. Piezometer and Groundwater Level Surveys

Measurements of the piezometer elevations and of water levels in piezometers were conducted by personnel from the Civil Research Department and TBTGS. The levels are reported as elevations relative to the average lake shoreline level of 182.88 m (600 ft) for the Thunder Bay area.

3. Groundwater Sampling

In general, the following water level measurement and sampling procedures were used by station personnel.

(a) Bailing

- Groundwater levels in each piezometer were measured and recorded. The water from each piezometer was bailed out with a hand-operated pump or a vacuum pump

- Four days later the water from each piezometer was bailed out again.

(b) Sampling

- One day after the second bailing about 1 L of groundwater from each piezometer was collected into an acid cleaned LPE (linear polyethylene) bottle.

- The waters' pH and conductivity were measured immediately with portable pH and conductivity meters.

TABLE I

TBTGS FUEL STORAGE AREA

PIEZOMETER INSTALLATION DETAILS

PIEZOMETER IDENTIFICATION	DEPTH BELOW GROUND (m)	DEPTH BELOW GROUND (ft)
P 79- 1-A (1)	3.06	10.04
P 79- 1-B	0.93	3.05
P 79- 2-A	3.98	13.06
P 79- 2-B	2.71	8.89
P 79- 2-C	1.81	5.94
P 79- 3-A	3.35	10.99
P 79- 3-B	1.42	4.66
P 79- 4-A	4.80	15.75
P 79- 4-B	3.50	11.48
P 79- 4-C	2.84	9.32
P 79- 5-A	8.52	27.95
P 79- 5-B	6.03	19.78
P 79- 5-C	4.47	14.67
P 79- 6-A	8.02	26.31
P 79- 6-B	5.54	18.18
P 79- 6-C	3.10	10.17
P 79- 7-A	6.24	20.47
P 79- 7-B	4.56	14.96
P 79- 7-C	1.79	5.87
P 79- 8-A	5.63	18.47
P 79- 8-B	3.83	12.57
P 79- 8-C	2.21	7.25
P 79- 9-A	4.65	15.26
P 79- 9-B	2.80	9.19
P 79- 9-C	1.71	5.61
P 79-10-A	5.06	16.60
P 79-10-B	3.65	11.98
P 79-10-C	2.67	8.76
P 79-11-A	3.51	11.52
P 79-11-B	2.83	9.29
P 79-12-A	4.40	14.44
P 79-12-B	3.62	11.88
P 79-12-C	2.02	6.63
P 79-13-A	3.87	12.70
P 79-13-B	2.96	9.71
P 79-13-C	1.38	4.53
P 79-14-A	3.61	11.84
P 79-14-B	2.30	7.55
P 79-14-C	1.54	5.05
P 80-15-A (2)	2.97	9.75
P 80-15-B	4.72	15.50
P 80-16-A	3.11	10.20
P 80-16-B	4.87	15.98
P 80-17-A	2.53	8.30
P 80-17-B	3.65	11.96
P 80-18-A	1.85	6.08
P 80-18-B	3.57	11.70
P 80-19-A	1.81	5.92
P 80-19-B	3.62	11.90
P 80-20-A	2.16	7.08
P 80-20-B	3.35	11.00

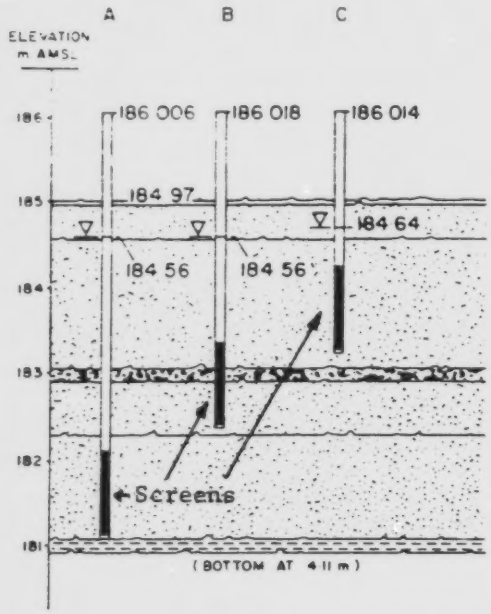
Note:

(1) P79 piezometers were installed by London Monenco Consultants Ltd (LMC) in 1979. Piezometer depths shown are taken from the LMC Baseline Report - Tables B-1 and B-2. The A piezometers are deepest followed by the shallower B and C piezometers.

(2) P80 piezometers were installed by Ontario Hydro in 1980. The B piezometers are deep and A shallow.

GROUND ELEVATIONS / CO-ORDINATES (A) 184 97 m AMSL (606 88 ft) / 4588 N, 5069 E
(B) 184 97 m AMSL (606 88 ft) / 4587 N, 5066 E
(C) 184 97 m AMSL (606 88 ft) / 4585 N, 5062 E

PIEZOMETER CONSTRUCTION



HYDROGEOLOGIC LOG

DEPTHS (m)	
0 - 0·03	ORGANIC DEBRIS, PEAT STRIPPED AWAY
0 03 - 0 46	SAND, BROWN, FINE TO COARSE WITH OCCASIONAL ROOTS
0 46 - 1 98	SAND, BROWN, FINE TO MEDIUM, SILTY WITH LAYERS OF GREY SILTY SAND WOOD FRAGMENTS NEAR BASE
1 98 - 2 13	PEAT; BROWN, SANDY, STRUCTURELESS
2 13 - 2 74	SAND; GREY, FINE TO MEDIUM, SLIGHTLY SILTY WITH FREQUENT ORGANIC LAYERS
2·74 - 3·96	SAND, GREY, FINE TO MEDIUM STIFF FROM 3 35 TO 3 96 m
3·96 - 4·11	CLAY; GREY, STIFF, SILTY

PIEZOMETER	DATE	WATER TABLE ELEVATION (m)	PERMEABILITY (cm/s)
P-79-2A	JUNE 14 SEPT 27	184·56 184·05	$8·8 \times 10^{-4}$
P-79-2B	JUNE 14 SEPT 27	184·56 184·06	$3·6 \times 10^{-4}$
P-79-2C	JUNE 14 SEPT 27	184·64 184·06	$3·0 \times 10^{-4}$

FIGURE 2

Thunder Bay Generating Station
Groundwater Monitoring Study
Coal Storage Area

TYPICAL

PIEZOMETER NEST P-79-2
HYDROGEOLOGIC LOG AND PIEZOMETER CONSTRUCTION

TABLE II

Water Level Measurements and Piezometer Construction Details
(Metric Units)

PIEZOMETER		GROUND	WATER LEVEL						STANDPIPE			SCREEN				
			ELEVATION (m)		DEPTH BELOW GROUND (m)		DEPTH BELOW STANDPIPE (m)									
IDENTIFICATION	CO-ORDINATES	ELEVATION (m)	JUNE 14	SEPT 27	JUNE 14	SEPT 27	JUNE 14	SEPT 27	ELEVATION (m)	HEIGHT ABOVE GROUND (m)*	DEPTH BELOW GROUND (m)	TYPE**	LENGTH (m)	DEPTH BELOW GROUND (m) from to	DEPTH BELOW STANDPIPE (m) from to
79-1-A	4307N, 4226E	184.63	184.24	184.16	0.39	0.47	1.40	1.48	185.638	1.01	3.06	1	0.74	2.20 - 2.93	2.94 - 3.67
79-1-B	4312N, 4226E	184.63	DRY	DRY	DRY	DRY	DRY	DRY	185.604	0.97	0.93	2	0.75	0.12 - 0.88	0.87 - 1.63
79-2-A	4588N, 5069E	184.97	184.56	184.05	0.41	0.91	1.45	1.95	186.006	1.04	3.98	2	0.99	2.94 - 3.93	3.93 - 4.92
79-2-B	4587N, 5066E	184.97	184.56	184.06	0.41	0.91	1.45	1.96	186.018	1.05	2.71	2	1.00	1.68 - 2.68	2.68 - 3.68
79-2-C	4585N, 5062E	184.97	184.64	184.06	0.33	0.92	1.37	1.96	186.014	1.04	1.81	2	1.00	0.78 - 1.78	1.78 - 2.78
79-3-A	4866N, 5631E	183.76	183.50	183.47	0.19	0.22	1.18	1.21	184.680	0.99	3.35	2	1.00	2.25 - 3.25	3.25 - 4.25
79-3-B	4866N, 5626E	183.76	183.49	183.49	0.34	0.34	1.26	1.26	184.753	0.92	1.42	2	1.00	0.39 - 1.39	1.39 - 2.39
79-4-A	4930N, 6036E	184.91	183.43	183.49	1.48	1.42	2.45	2.39	185.878	0.97 (0.28)	4.80	2	1.00	3.76 - 4.76	4.71 - 5.71
79-4-B	4930N, 6039E	184.91	183.43	183.51	1.48	1.40	2.43	2.35	185.856	0.95 (0.25)	3.50	3	0.46	3.00 - 3.46	3.95 - 4.41
79-4-C	4930N, 6042E	184.91	183.43	183.53	1.48	1.38	2.47	2.37	185.897	0.99 (0.30)	2.84	3	0.46	2.38 - 2.84	3.33 - 3.79
79-5-A	4984N, 6686E	185.48	183.34	183.43	2.13	2.05	3.01	2.95	186.380	0.90 (0.73)	8.52	1	0.46	8.03 - 8.49	8.93 - 9.39
79-5-B	4978N, 6686E	185.48	183.42	183.42	2.12	2.06	3.01	3.01	186.433	0.95 (0.83)	6.03	3	0.46	5.54 - 6.00	6.49 - 6.95
79-5-C	4974N, 6686E	185.48	183.42	183.42	2.11	2.06	3.07	3.06	186.486	1.01 (0.82)	4.47	4	0.40	4.01 - 4.41	5.02 - 5.42
79-6-A	4543N, 6741E	185.14	183.85	183.43	1.32	1.71	2.24	2.63	186.057	0.92 (0.70)	8.02	1	0.46	7.53 - 7.99	8.45 - 8.91
79-6-B	4551N, 6741E	184.93	183.43	183.42	1.54	1.51	2.41	2.42	185.943	0.91 (0.48)	5.54	3	0.46	5.06 - 5.52	5.97 - 6.43
79-6-C	4560N, 6741E	184.64	183.43	183.43	1.73	1.21	2.20	2.20	185.633	0.99 (0.28)	3.10	3	0.46	2.61 - 3.07	3.60 - 4.06
79-7-A	4039N, 6661E	184.21	183.52	183.54	0.69	0.67	1.75	1.73	185.270	1.06 ( )	6.24	4	0.40	5.78 - 6.18	6.84 - 7.24
79-7-B	4045N, 6611E	184.57	183.53	183.56	1.04	1.01	2.07	2.05	185.605	1.04 ( )	4.56	3	0.46	4.08 - 4.54	5.11 - 5.57
79-7-C	4051N, 6661E	184.72	183.57	183.53	1.18	1.19	2.23	2.24	185.773	1.05 ( )	1.79	3	0.46	1.30 - 1.76	2.35 - 2.81
79-8-A	3808N, 6669E	184.29	183.49	183.39	1.10	0.91	1.80	1.91	185.293	1.00 (0.37)	5.63	4	0.40	5.17 - 5.57	6.17 - 6.57
79-8-B	3803N, 6669E	184.53	183.26	183.38	1.27	1.15	2.25	2.13	185.510	0.98 (0.62)	3.81	3	0.46	3.35 - 3.81	3.35 - 3.81
79-8-C	3798N, 6669E	184.47	183.31	183.38	1.16	1.08	2.16	2.06	185.449	0.98 (0.52)	2.21	3	0.46	1.71 - 2.17	2.69 - 3.15
79-9-A	3575N, 6575E	184.00	183.42	183.36	0.58	0.64	1.55	1.62	184.978	0.98	4.65	3	0.46	4.15 - 4.61	5.13 - 5.59
79-9-B	3575N, 6578E	184.00	183.43	183.36	0.57	0.64	1.54	1.61	184.970	0.97	2.80	4	0.40	2.34 - 2.74	3.31 - 3.71
79-9-C	3575N, 6581E	184.00	183.42	183.36	0.58	0.64	1.57	1.63	184.994	0.99	1.71	3	0.46	1.22 - 1.68	2.21 - 2.67
79-10-A	3810N, 6452E	184.51	182.88	182.88	1.63	0.85	2.65	1.87	185.531	1.02 (0.71)	5.06	4	0.40	4.61 - 5.01	5.63 - 6.03
79-10-B	3810N, 6455E	184.51	182.90	183.66	1.61	0.86	2.62	1.87	185.527	1.01 (0.70)	3.65	3	0.46	3.16 - 3.62	4.17 - 4.63
79-10-C	3810N, 6457E	184.51	182.88	183.64	1.63	0.87	2.65	1.89	185.535	1.02 (0.73)	2.67	3	0.46	2.18 - 2.64	3.20 - 3.66
79-11-A	4051N, 5226E	184.75	183.39	183.91	1.36	0.84	2.39	1.87	185.780	1.03	3.51	3	0.46	3.02 - 3.48	4.05 - 4.51
79-11-B	4046N, 5226E	184.75	183.38	183.93	1.37	0.83	2.40	1.85	185.781	1.03	2.83	3	0.46	2.34 - 2.80	3.37 - 3.83
79-12-A	3429N, 6562E	184.27	183.41	183.38	0.85	0.89	1.25	1.28	184.662	0.19	4.40	4	0.40	1.99 - 4.33	4.38 - 4.78
79-12-B	3433N, 6562E	184.27	183.41	183.37	0.86	0.90	1.29	1.34	184.708	0.44	3.42	3	0.46	3.13 - 3.59	3.57 - 4.03
79-12-C	3437N, 6562E	184.27	183.41	183.38	0.86	0.90	1.35	1.39	184.764	0.49	2.02	3	0.46	1.55 - 2.01	2.04 - 2.50
79-13-A	3167N, 6377E	183.91	183.41	183.38	0.50	0.53	1.52	1.55	184.935	1.02	3.87	3	0.46	3.39 - 3.85	4.41 - 4.87
79-13-B	3171N, 6377E	183.91	183.42	183.39	0.49	0.52	1.49	1.52	184.909	1.00	2.96	3	0.46	2.47 - 2.93	3.47 - 3.93
79-13-C	3175N, 6377E	183.91	183.44	183.40	0.47	0.50	1.46	1.50	184.906	1.00	1.38	3	0.46	0.89 - 1.35	1.89 - 2.35
79-14-A	3055N, 6086E	184.06	183.39	183.35	0.67	0.72	1.75	1.79	185.134	1.07	3.61	2	1.00	2.58 - 3.58	3.65 - 4.65
79-14-B	3055N, 6090E	184.06	183.37	183.35	0.69	0.71	1.71	1.73	185.084	1.02	2.30	3	0.46	1.81 - 2.27	2.83 - 3.29
79-14-C	3055N, 6094E	184.06	183.37	183.35	0.69	0.72	1.75	1.78	185.125	1.06	1.54	3	0.46	1.05 - 1.51	2.11 - 2.57

**TYPE 1 - WESCO, PVC, No. 10 slot 'wire wound' screen; length = 0.71 m (2.41 ft); I.D. = 3.8 cm, (1.5 in); 12 cm (5 in) unscreened section at base.

TYPE 2 - PVC pipe with No. 10 machined horizontal slots; length = 1.00 m (1.28 ft); I.D. = 3.8 cm, (1.5 in); 3 cm (1 in) unscreened section at base.

TYPE 3 - PVC pipe with No. 10 machined horizontal slots: length = 0.46 m (1.50 ft); I.D. = 3.8 cm, (1.5 in); between 3 and 6 cm (1-2½ in) unscreened section at base.

TYPE 4 - JOHNSON, PVC, No. 10 slot 'wire wound' screen; length = 0.34 m (1.10 ft); I.D. = 3.2 cm, (1.25 in); 6 cm (2½ in) unscreened section at base.

* Recorded 'height above ground' values were measured on September 24 after additional fill had been placed.

NOTE: Although the standpipe elevations have been determined to the nearest millimetre, water levels have been rounded to the nearest centimetre because of the small water level changes which result when the weighted tape measure is immersed.

From: London Monenco Consultants Limited, Baseline Report - February, 1980

(c) Preparation

- All samples collected were stored in a refrigerator at about 4°C.

- The samples were filtered as soon as possible using 0.45 m prewashed Millipore filters.

- A pretreated 500 mL LPE bottle was filled with the filtrate to which were added 2.5 mL of "ULTREX" HNO_3.

- A portion of the remaining filtrate was used for selected field tests.

(d) Shipping

- The remaining filtrate (from c) was kept at about 4°C in a cooler with ice packs, and shipped by air, together with the acidifed samples, to Research Division, for analysis.

4. Groundwater Tests and Analyses

(a) Partial Analyses at TBTGS

The parameters determined by TBTGS personnel were pH, conductivity, acidity and alkalinity and on some occasions Cl, SO_4, Na, Ca, Mg, Fe, Mn and B.

(b) Comprehensive Analyses - Research Division

Comprehensive chemical analyses of the groundwater samples were carried out by the Analytic Services Section of the Chemical Research Department. The characteristics determined are shown below:

pH	PO_4*	Ba	Mn	Ni
Conductivity, mS/m	F	Al	V	Sn
Alkalinity as $CaCO_3$	Ca	Si	Cr	Zn
Acidity as $CaCO_3$	Mg	Th	Cu	As
SO_4	Na	Be	Mo	B
Cl	K	Fe	Ag	Pb
NO_3	Sr	Ti	Co	Se
			Hg	Cd

* The 'soluble reactive phosphorus' content of a filtered sample

(c) Analytical Methods

The analytical methods used were mainly those outlined in the Standard Methods for the Examination of Water and Wastewater, published by the American Public Health Association (14th

Edition)/6/. Ion chromatography, neutron activation and other instrumental techniques, currently in general use by the Analytic Services Section, were also used for some determinations.

5. Rationale

(a) Field Tests

Because some characteristics of natural waters change after sampling, pH and conductivity were measured in the field and acidity, alkalinity and the other parameters were determined in the station's laboratory on stored samples.

(b) Comprehensive and Partial Analyses

Because of their complexity and the time required, comprehensive analyses were carried out by the Analytic Section of the Chemical Research Department, Research Division.

(c) Parameter Significance

Of the parameters determined, pH, conductivity, acidity, alkalinity and concentrations of SO_4 and Fe are considered as the main indicators of coal leachates. These parameters were used to distinguish between contaminated groundwaters and the local natural waters.

The above indicators of coal leachates are common to both the bituminous and the lignite coals. However, the two types of leachates differ in their acidity and alkalinity levels. Leachates from bituminous coal are usually very acidic (low pH and low alkalinities). Leachates from freshly stockpiled lignite coal are usually alkaline (pH>7 and low acidity)/7/.

Sulphate is considered to be the most reliable indicator of the presence of bituminous coal leachates. High iron concentrations and low pH levels (high acidity and low alkalinity) are also indicative but they are more prone to modification on passage through the soil. The remaining parameters are less reliable contaminant indicators but do help in general characterization of water quality.

RESULTS OF FIELD AND LABORATORY WORK CONDUCTED IN 1984

1. Piezometer Network Level Surveys

The 1984 piezometer elevation survey was carried out by the Civil Research Department on May 15. The 1984 results, together with those obtained from 1979 through 1983 are summarized in Table III. Locations of the piezometers are shown in Figure 1.

TABLE III

FUEL STORAGE AREA - GROUNDWATER QUALITY STUDIES - 1979-1984
THUNDER BAY TGS EXTENSION

PIEZOMETER REFERENCE LEVELS
(1979-1984)

Piezometer Identification		Piezometer Reference Levels, m (Relative to Average Shoreline Level of 182.88 m)									
		Date Surveyed									
		(1) 1979	(2) 1980	July 16/81	Nov 2/81	June 9/82	Nov 3/82	May 18/83	May 15/84	Δ	Δ'
P79	1A	2.76	-	-	-	-	-	-	-	-	-
	1B	2.72	-	-	-	-	-	-	-	-	-
P79	2A	3.13	-	-	-	-	-	3.14	-	-	+0.01
	2B	3.14	-	-	-	-	-	3.14	-	-	0.00
	2C	3.13	-	-	-	-	-	3.13	-	-	0.00
P79	3A	1.80	-	-	-	-	-	2.06	2.09	+0.03	+0.29
	3B	1.87	-	-	-	-	-	2.07	2.10	+0.03	+0.23
P79	4A	3.00	-	2.99	3.05	3.01	3.00	3.01	3.00	-0.01	0.00
	4B	2.98	-	2.94	3.01	2.97	2.95	2.96	2.96	0.00	-0.02
	4C	3.02	-	2.97	3.04	2.99	2.98	2.99	2.98	-0.01	-0.04
P79	5A	3.50	-	3.42	3.55	3.53	3.52	3.56	3.56	0.00	+0.06
	5B	3.55	-	3.48	3.61	3.59	3.58	3.62	3.63	+0.03	+0.08
	5C	3.61	-	3.52	3.65	3.62	3.46	3.64	3.66	+0.02	+0.05
P79	6A	3.18	-	3.17	3.30	3.29	3.28	3.30	3.32	+0.02	+0.14
	6B	2.96	-	3.00	3.14	3.15	3.14	3.21	3.26	+0.05	+0.30
	6C	2.75	-	2.73	2.87	2.87	2.86	2.90	2.95	+0.05	+0.20
P79	7A	2.39	-	2.42	2.42	2.41	2.41	2.40	2.40	0.00	+0.01
	7B	2.73	-	2.72	2.74	2.72	2.71	2.71	2.71	0.00	-0.02
	7C	2.89	-	2.93	2.93	2.91	2.70	2.90	2.90	0.00	+0.01
P79	8A	2.41	-	2.42	2.46	2.45	2.44	2.44	2.44	0.00	+0.03
	8B	2.63	-	2.65	2.68	2.66	2.65	2.65	2.65	0.00	+0.02
	8C	2.57	-	2.58	2.64	2.63	2.63	2.63	2.64	+0.01	+0.07
P79	9A	2.10	-	2.38	2.37	2.46	2.45	2.50	2.54	+0.04	+0.44
	9B	2.09	-	2.43	2.43	2.53	2.44	2.53	2.58	+0.05	+0.49
	9C	2.11	-	2.70	2.39	2.49	2.48	2.58	2.62	+0.04	+0.51
P79	10A	2.65	-	-	-	-	-	-	-	-	-
	10B	2.64	-	-	-	-	-	-	-	-	-
	10C	2.66	-	-	-	-	-	-	-	-	-
P79	11A	2.90	-	-	-	-	-	2.91	-	-	+0.01
	11B	2.90	-	-	-	-	-	2.91	-	-	+0.01
P79	12A	1.78	-	2.19	2.05	2.08	2.07	2.11	2.14	+0.03	+0.36
	12B	1.83	-	2.18	2.15	2.19	2.19	2.30	2.33	+0.03	+0.50
	12C	1.88	-	2.08	2.17	2.18	2.17	2.24	2.26	+0.02	+0.38
P79	13A	2.06	-	2.16	2.13	2.17	2.16	2.18	2.18	0.00	+0.12
	13B	2.03	-	2.17	2.14	2.15	1.94	2.16	2.19	+0.03	+0.16
	13C	2.03	-	2.22	2.19	2.19	2.19	2.22	2.23	+0.01	+0.20
P79	14A	2.25	-	2.33	2.33	2.35	2.33	2.33	2.37	+0.04	+0.12
	14B	2.20	-	2.34	2.30	2.35	2.34	2.35	2.39	+0.04	+0.19
	14C	2.25	-	2.37	2.29	2.29	2.28	2.27	2.28	+0.01	+0.03
P80	15A	-	3.60	3.47	3.58	3.54	3.53	3.57	3.58	+0.01	-0.02
	15B	-	3.56	3.51	3.61	3.58	3.57	3.61	3.63	+0.02	+0.07
P80	16A	-	3.38	3.26	3.36	3.37	3.36	3.41	3.17(3)	-0.24	-0.21
	16B	-	3.31	3.34	3.43	3.45	3.44	3.51	3.42	-0.09	+0.11
P80	17A	-	3.35	2.87	3.01	3.02	3.01	3.08	3.14	+0.06	-0.21
	17B	-	2.95	3.28	3.41	3.42	3.42	3.48	3.55	+0.07	+0.60
P80	18A	-	2.17	2.25	2.21	2.21	2.21	2.22	2.25	+0.03	+0.08
	18B	-	2.17	2.24	2.20	2.19	2.18	2.21	2.24	+0.03	+0.07
P80	19A	-	2.27	2.31	2.27	2.24	2.22	2.21	2.21	0.00	-0.06
	19B	-	2.66	2.70	2.66	2.62	2.61	2.59	2.60	+0.01	-0.06
P80	20A	-	2.92	2.94	2.87	-	-	-	-	-	-0.05
	20B	-	2.54	2.55	3.14	-	-	-	-	-	+0.60

(1) London Monenco Consultants Ltd., Baseline Report for Ontario Hydro Thunder Bay TGS Extension - Groundwater Monitoring Study - Coal Storage Area (B-2) Feb. 1980.

(2) Ontario Hydro data.

(3) Top of piezometer broken off.

Δ Change from previous levels (m).

Δ' Change from the original (1979 or 1980) levels, m

2. Groundwater Level Surveys

Measurements of groundwater levels in piezometers on the perimeters of the fuel piles were carried out on four occasions during 1984. The results are shown in Table IV. Groundwater levels from 1979 through 1984 are presented in Appendix A.

Lake Superior water levels (relative piezometer monthly means) obtained from Fisheries and Oceans, Services Branch, Ottawa, and monthly total precipitation values, obtained from Environment Canada, Canadian Climate Centre, Downsview, for the Thunder Bay area are summarized in Table V. Total precipitation values from 1979 through 1984 are listed in Appendix B.

3. Groundwater Characteristics

The detailed analytical results obtained at Thunder Bay TGS and at Research on groundwater samples taken on May 17 and July 20 are shown in Appendix C. The limited results obtained at Thunder Bay TGS are also included in the summary. However, because they were obtained on the same samples that were submitted for the comprehensive analysis, the TBTGS results are shown under a different date (one day after the actual sampling) to avoid computer problems in recalling the field data in the future.

DISCUSSION OF FIELD AND LABORATORY WORK CONDUCTED IN 1984

1. Piezometer Reference Levels

The piezometer reference levels for 1984, given in Table I, show that from May 18, 1983 to May 15, 1984, the levels of 26 piezometers rose, four dropped and nine remained the same. The greatest level increases occurred for piezometer 17A and 17B (0.06 m and 0.07 m), 6B and 6C (0.05 m), 9A, 9B, 9C (0.04 m, 0.05 m and 0.04 m) and 14A and 14B (0.04 m). Piezometer nests 6 and 17 are located east of the lignite pile close to the eroded shoreline. Piezometer nest 9 is located south of the collecting lagoon and nest 14 south of the bituminous coal pile. The greatest reference level decreases occurred for piezometers 16A and 16B. These piezometers are located north of the lignite pile, close to and on the inside of the drainage ditch and somewhat distant from the shore.

Comparison of the original (1979-80) piezometer reference levels with the 1984 levels shows that most reference levels had increased. The greatest increases occurred with piezometers in nests 3, 6, 9, 12, 13, 14, and piezometers 17B and 20B. With the exception of piezometers 3A, 3B, 20A and 20B, for which only limited data are available, the remaining piezometers are located along the eastern shoreline. The only major decrease in

TABLE IV

FUEL STORAGE AREA - GROUNDWATER QUALITY - 1984
THUNDER BAY TGS EXTENSION

RELATIVE PIEZOMETER AND LAKE WATER LEVELS - 1984
(Relative to Average Shoreline Level of 182.88 m)

Piezometer Identification	Relative Water Levels in Piezometers (m)			
	Dates Measurements Taken			
	May 14, 1984	July 6, 1984	July 19, 1984	Oct. 26, 1984
P79 1A	1.33	1.23	1.21	1.17
P79 1B	1.32	1.23	-	1.16
P79 2A	-	-	-	-
P79 2B	-	-	-	-
P79 2C	-	-	-	-
P79 3A	0.83	0.70	0.68	0.66
P79 3B	0.82	0.72	-	0.67
P79 4A	0.45	0.57	0.53	0.95
P79 4B	0.45	0.58	-	0.48
P79 4C	0.43	0.57	-	0.93
P79 5A	0.32	0.52	-	0.41
P79 5B	0.33	0.54	-	0.41
P79 5C	0.35	0.54	0.51	0.41
P79 6A	0.25	0.56	-	0.38
P79 6B	0.27	0.51	0.50	0.39
P79 6C	0.23	0.47	0.45	0.35
P79 7A	-0.12	0.17	-	0.07
P79 7B	-0.12	0.19	-0.02	0.06
P79 7C	-0.05	0.22	-	0.09
P79 8A	-0.23	0.14	-	0.06
P79 8B	-0.21	0.14	-0.02	0.05
P79 8C	-0.11	0.21	-	0.10
P79 9A	0.25	0.41	-	0.34
P79 9B	0.25	0.41	-	0.35
P79 9C	0.27	0.42	-	0.36
P79 10A	-	-	-	-
P79 10B	-	-	-	-
P79 10C	-	-	-	-
P79 11A	0.67	1.13	-	1.02
P79 11B	0.71*	1.13	-	1.02
P79 12A	0.28	0.44	-	0.37
P79 12B	0.29	0.44	-	0.37
P79 12C	0.26	0.43	0.41	0.36
P79 13A	0.38	0.49	-	0.20
P79 13B	0.39	0.47	0.45	0.21
P79 13C	0.33	0.43	0.43	0.20
P79 14A	0.30	0.42	0.43	0.38
P79 14B	0.29	0.42	0.43	0.38
P79 14C	0.28	0.42	0.42	0.38
P80 15A	0.55	0.82	0.73	0.54
P80 15B	1.18	1.41	1.18	0.90
P80 16A	0.70**	-	-	0.73
P80 16B	0.66	0.98	0.85	0.72
P80 17A	0.48	0.85	0.64	0.49
P80 17B	0.28	1.12	1.02	0.67
P80 18A	0.42	0.43	0.45	0.39
P80 18B	0.31	0.44	0.44	0.39
P80 19A	0.29	0.40	0.40	0.34
P80 19B	0.31	0.42	0.44	0.37
P80 20A	-	-	-	-
P80 20B	-	-	-	-
Lake Level (1)	0.23	0.39	0.39	0.35

(1) Relative average monthly lake levels (relative to 182.88 m average lake level) for Station 10050, Thunder Bay Harbour. Data obtained from Marine Environmental Data, Services Branch, Fisheries and Oceans, Ottawa.

* Piezometer cap missing
** Piezometer top broken

TABLE V

LAKE SUPERIOR WATER LEVELS AND TOTAL PRECIPITATION
1979 - 1984

Year	Month	Lake Superior Water Level m (1) (monthly means)	Total Precipitation mm (2)	Year	Month	Lake Superior Water Level m (1) (monthly means)	Total Precipitation mm (2)
1979	January	-0.02	16.2	1982	January	-0.07	58.1
	February	-0.05	61.3		February	-0.11	11.4
	March	-0.01	102.9		March	-0.14	64.8
	April	0.05	55.4		April	-0.07	42.0
	May	0.25	96.5		May	0.09	77.1
	June	0.40	52.4		June	0.15	73.3
	July	0.43	37.8		July	0.24	200.3
	August	0.42	68.1		August	0.30	126.3
	September	0.40	47.5		September	0.31	50.1
	October	0.35	91.1		October	0.38	141.6
	November	0.34	15.9		November	0.40	52.4
	December	0.26	23.9		December	0.34	43.2
1980	January	0.19	57.2	1983	January	0.29	37.1
	February	0.13	11.9		February	0.23	24.2
	March	0.05	36.9		March	0.20	42.1
	April	0.06	20.5		April	0.21	59.4
	May	0.12	32.8		May	0.25	47.9
	June	0.17	58.7		June	0.34	67.9
	July	0.21	127.7		July	0.38	62.4
	August	0.24	124.0		August	0.36	108.0
	September	0.29	174.9		September	0.34	83.8
	October	0.26	63.5		October	0.38	74.7
	November	0.20	40.7		November	0.35	103.7
	December	0.09	47.5		December	0.29	37.7
1981	January	0.00	7.8	1984	January	0.22	2.1
	February	-0.04	55.5		February	0.17	32.4
	March	-0.05	23.1		March	0.12	15.7
	April	0.05	49.4		April	0.13	26.5
	May	0.13	59.5		May	0.23	51.7
	June	0.22	170.2		June	0.33	120.7
	July	0.25	7.4		July	0.39	97.0
	August	0.23	85.6		August	0.40	86.5
	September	0.16	38.1		September	0.37	46.5
	October	0.14	71.4		October	0.35	82.6
	November	0.08	23.6		November	0.31	32.1
	December	0.01	30.2		December	0.27	71.0

(1) Calculated difference between monthly means and the average shoreline level of 182.88 m. From Marine Environmental Data for Thunder Bay (Harbour), Station 10050, obtained from the Services Branch, Fisheries and Oceans, Ottawa.

(2) Total monthly precipitation of rain and snow, calculated from 'Total Daily Precipitation of Rain and Snow' data, for Thunder Bay A (airport), provided by Environment Canada, Atmospheric Environment Service, Canadian Climate Centre, Downsview, Ontario.

reference level occurred with piezometer 17A located on the east side of the lignite pile close to the drainage ditch. Some of the decreased piezometer reference levels could be attributed to construction activities at the site such as the installation of drainage ditches. The majority of piezometer reference level changes, particularly the increases, could have been caused by possible increased ground pressures caused by freezing.

2. Groundwater Levels and Flows

The piezometer groundwater level data acquired in 1984 (from May 14 to Oct 26) and presented in Table IV, show that groundwater levels in the fuel storage areas varied from a low of -0.23 m below the average shoreline water level of 182.88 m (the reference level used since 1980) in piezometer 8A on May 14 to a high of 1.41 m in piezometer 15B on July 6. Other low (negative) levels in May were present in piezometers 7A ,7B, 7C, 8B and 8C and the high levels, throughout the testing period, were in piezometers 1A, 1B, 11A and 11B. The pattern of low and high water levels during 1984 is essentially the same as that in 1982 and 1983. The lowest groundwater levels exist in the area south-east of the lignite pile. High ground water levels exist in the areas north and west of the lignite pile. This pattern of groundwater levels and flows, illustrated in Figure 3, is similar to that observed in the previous years.

The relationships between the groundwater levels, as represented by the water levels of several selected piezometers, the lake water levels and total precipitation, illustrated in Figure 4, show mainly that the water levels covered a greater range (lows to highs) towards the end of spring than they did in the fall. Although there appears to be no correlation, in gerneral, between groundwater levels and lake water levels groundwater levels in piezometers 16B, 6A, 12A & 14A, increased (relative to lake levels) after heavy precipitation in June. As in previous years, the changes in groundwater levels appear to be seasonal and somewhat affected by significant precipitation rather than influenced by lake water levels.

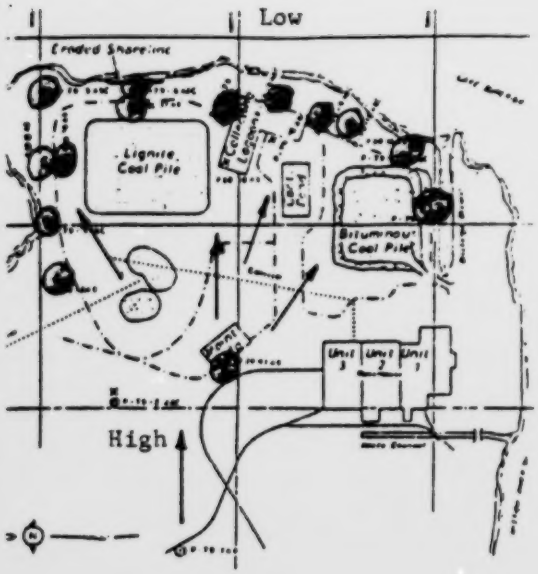
3. Groundwater Quality

The complete summary of groundwater analyses for 1984 appears in Appendix C. The specific discussion of 1984 groundwater quality has been included within the discussion of historical trends and outliers in the next section. This is justified by the consistency of groundwater chemistry which is addressed in the Statistical Analysis section.

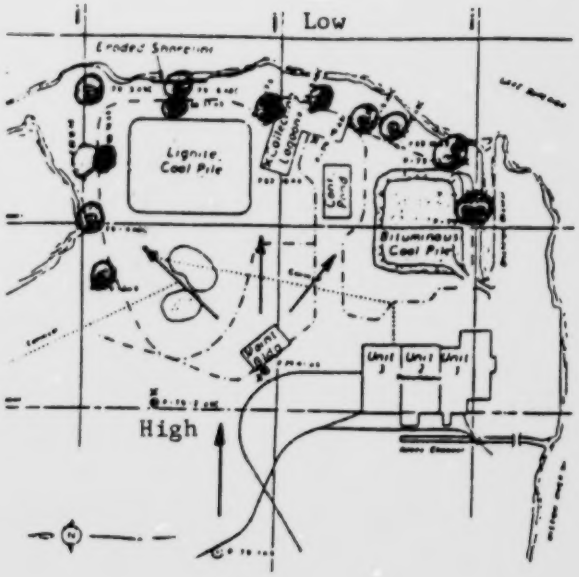
FUEL STORAGE AREA GROUNDWATER FLOWS

1984

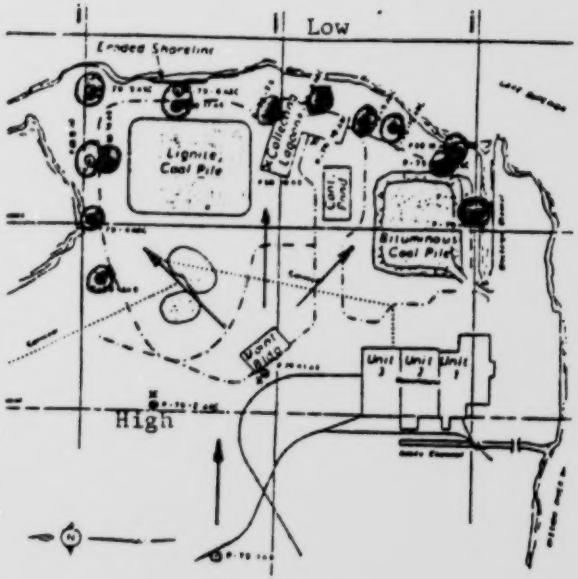
May 14/84



Jul. 6/84



Oct. 26/84



Relative Piezometer Levels Above 182.88 m

Direction of Water Flow

-0.23 to 0.25 m

0.26 to 0.59 m

0.60 to 0.99 m

1.0 to 1.33 m

Figure 3

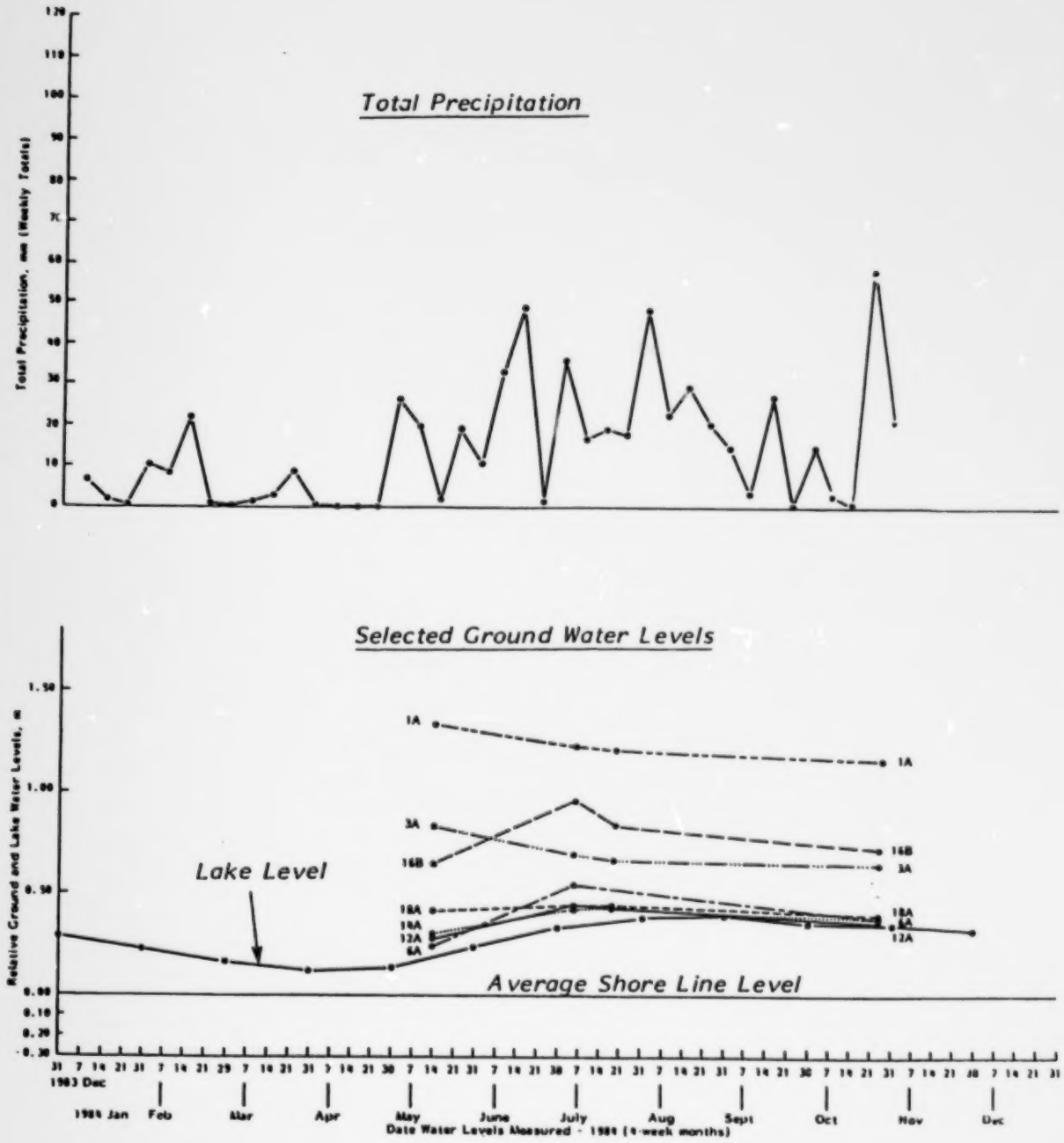


FIGURE 4

FUEL STORAGE AREA GROUND AND LAKE WATER LEVELS (m)*
AND TOTAL PRECIPITATION (mm)

*(Relative to Average Lake Shoreline Level of 182.88 m)

HISTORICAL SUMMARY AND ANALYSIS

INVESTIGATION OF OUTLIERS

As data was accumulated and reported every year certain observations were made and an attempt was made to explain outliers in terms of leachate formation/migration or natural site variations. Since sufficient data had not been collected until this point to allow a statistical analysis, these methods of visual inspection were relied upon heavily. There were two methods used to aid in the evaluation of the large amounts of data. Piper trilinear diagrams were used for some time to summarize major ion chemistry and recently, selected piezometers were specifically evaluated for trends or major changes in significant analytes.

1. Piper Diagrams

Piper trilinear diagrams have been routinely used to aid in the identification of outliers. In effect, Piper diagrams are 8 parameter visual correlation diagrams which serve to emphasize trends in major ion chemistry. Any consistent migration of points from the major groupings is indicative of water quality changes which require further, detailed explanation.

Since the start of the project there have been three groups of points in the Piper diagrams. Two of the groups are quite distinct and the third group may be labelled as 'transitional'. The first group of points represent waters from acidic piezometers 12C, 13B, 13C, 14A, 14B, 14C, 18A, 18B, 19A, and 19B, all located in the immediate vicinity of the bituminous coal pile. These points are all found at the apex of the triangular anion plot in Figures 5 and 6. These waters contain little or no alkalinity but have high sulphate values. The second group of points represents natural or unaffected groundwaters at the site. The values of SO_4 + Cl ions are generally below 40% of the anion total and alkalinity makes up the balance. The third, transitional, set of points is primarily made up of waters from piezometers 6B, 6C, and 17A. Throughout the history of the site, these piezometers have had relatively higher (>30% of the total anion) sulphate values than the natural waters. The reasons for these differences are not altogether clear as there could be some influence from coal pile drainage from the lignite pile and from the collecting lagoon. However, the stability of the transitional group is remarkable over the time period and it is questionable whether any explanation other than natural variation is possible.

The Piper diagrams for May 17 and July 20, 1984 surveys have been included in this section (see Figures 5 and 6) as they are typical of the majority of diagrams of major ion chemistry

FIGURE 5

MAJOR ION CHEMISTRY
TBTGS FUEL
MAY 17 1984
TYPE - WATER
FUEL STORAGE AREA GROUNDWATER QUALITY - IBTGS

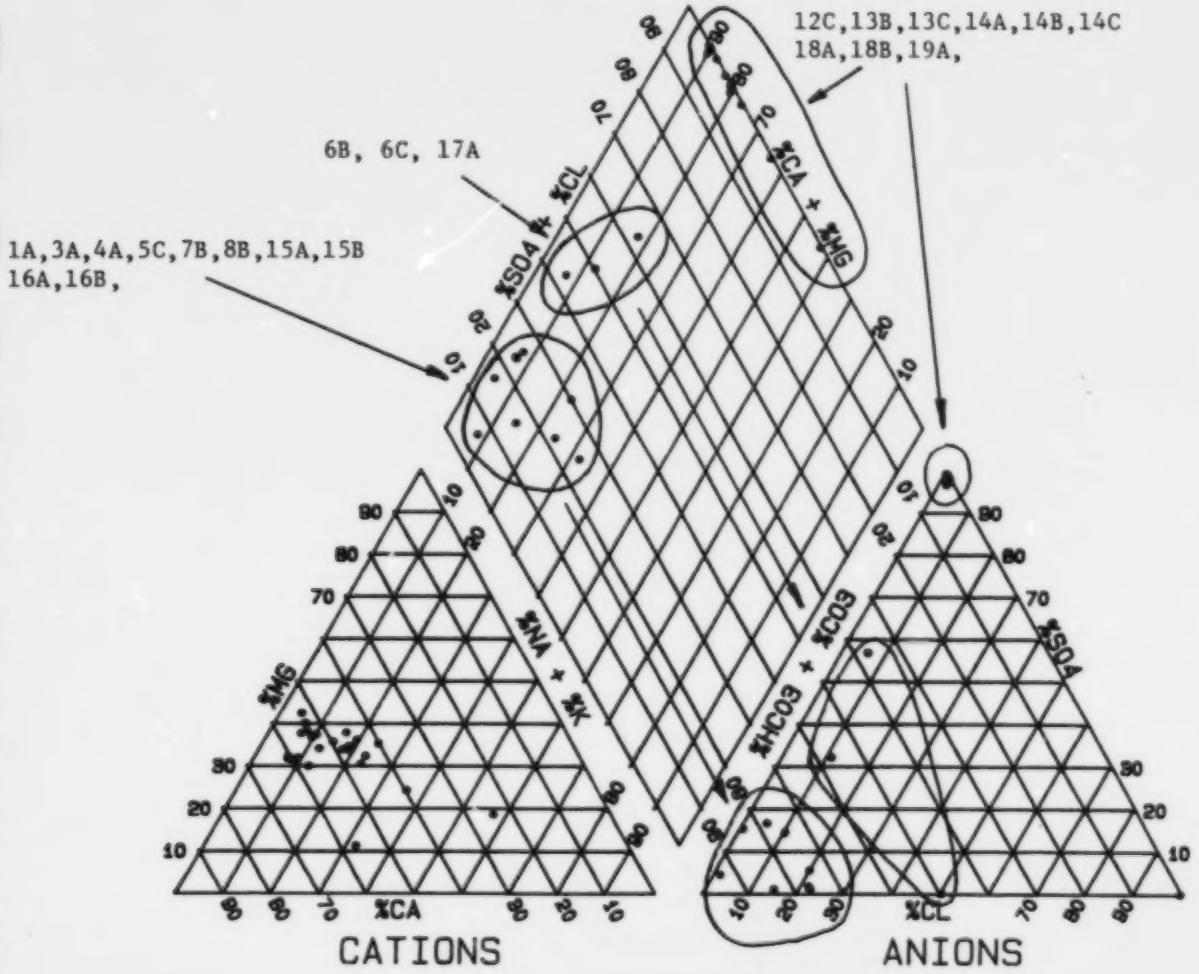
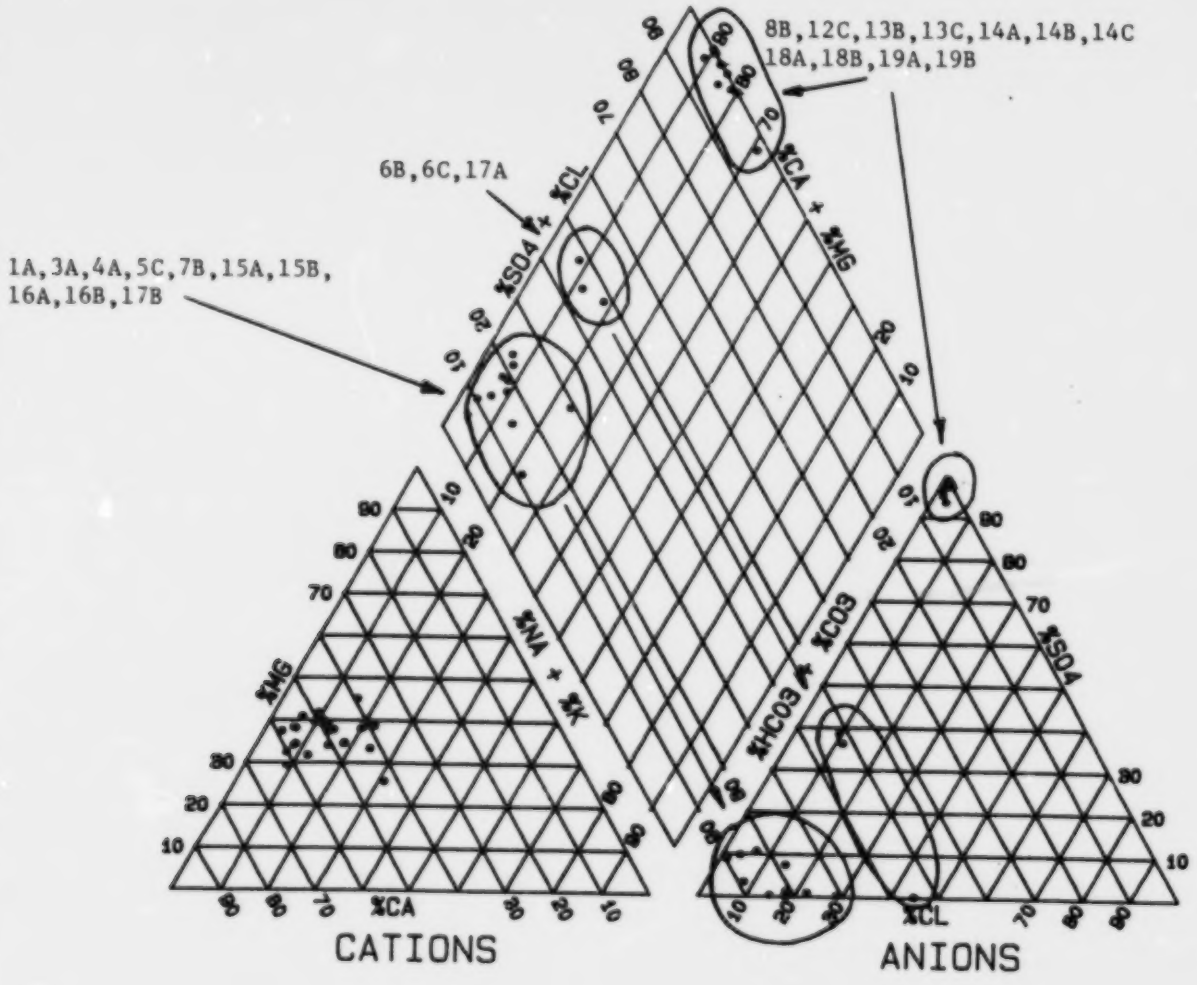


FIGURE 6

MAJOR ION CHEMISTRY
TBTGS FUEL
JULY 20 1984
TYPE - WATER
FUEL STORAGE AREA GROUNDWATER QUALITY - TBTGS



85-179

produced for previous yearly summaries. The magnitude of the parameter excursions from the main group of points is similar to those observed throughout the site history and the major groupings of points have remained stable during the study period.

2. Plots of Analytes for Selected Piezometers

In the 1983 site report /8/ 6 piezometers were chosen to provide early indications of groundwater contamination by coal pile leachate.

These piezometers (4A, 13B, 14A, 16A, 17A, 19A) were chosen after an historical assessment of data indicated that they were representative of the two different types (acidic and natural) of waters which have been monitored at the site from the beginning of the study.

The data for these piezometers have been augmented with the 1984 data. The plots of pH, HCO_3 alkalinity, acidity (to pH 8.3), conductivity, iron and sulphate versus time are shown as Figures 7-12.

The plot of pH vs Time (Figure 7) indicates that piezometers 13B, 14A and 19A showed consistently low pH values which are indicative of coal pile leachate formation.

The plot of HCO_3 alkalinity vs Time (Figure 8) is consistent in that piezometers 13B, 14A and 19A had virtually no alkalinity associated with them during the monitoring period.

The plot of Acidity vs Time (Figure 9) is complementary to the alkalinity plot and only those piezometers which have always displayed low pH and alkalinity appear (13B, 14A and 19A).

The plots of conductivity (Figure 10), iron (Figure 11) and sulphate (Figure 12) vs Time all show consistently elevated values for piezometers 13B, 14A and 19A.

It is apparent from analysis of all of the diagrams that there are indeed two distinct groups of waters. The acidic waters in piezometers 13B, 14A and 19A have low pH and elevated conductivity, iron and sulphate whereas waters in piezometers 4A, 16A and 17A are nearly neutral and are more representative of natural groundwaters in the area. However,waters in piezometers 17A (identified as 'transitional' in the section on Piper diagrams) had consistently more iron and sulphate than the waters in the other two piezometers.

The location of the piezometers is a significant factor as the acidic piezometers are associated with the bituminous coal pile while the group of unaffected piezometers is associated with the

FIGURE 7

TBTGS FUEL - SELECTED BOREHOLES

pH (Lab) vs TIME

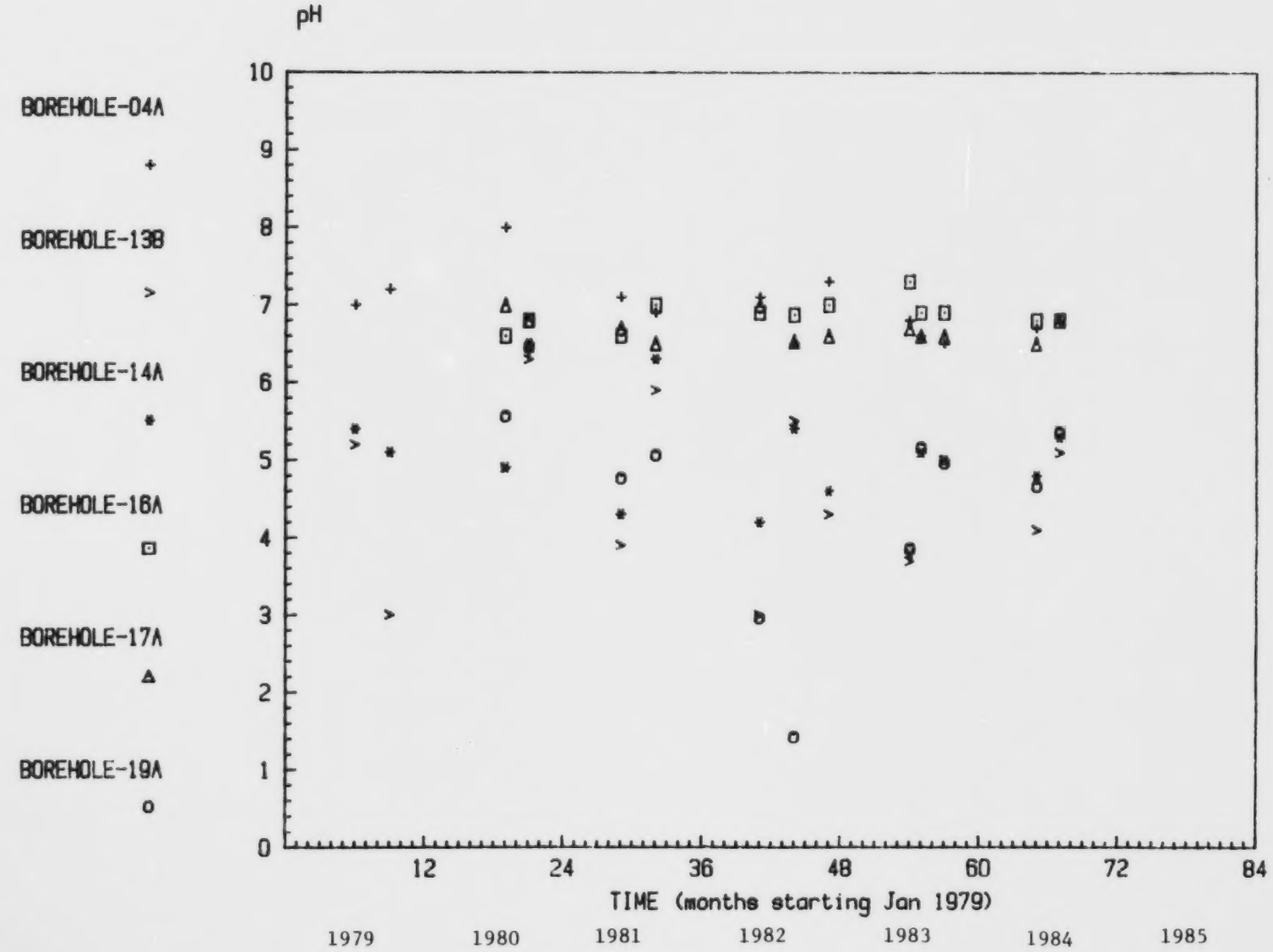


FIGURE 8

TBTGS FUEL - SELECTED BOREHOLES

HCO3 ALKALINTY (Lab) vs TIME

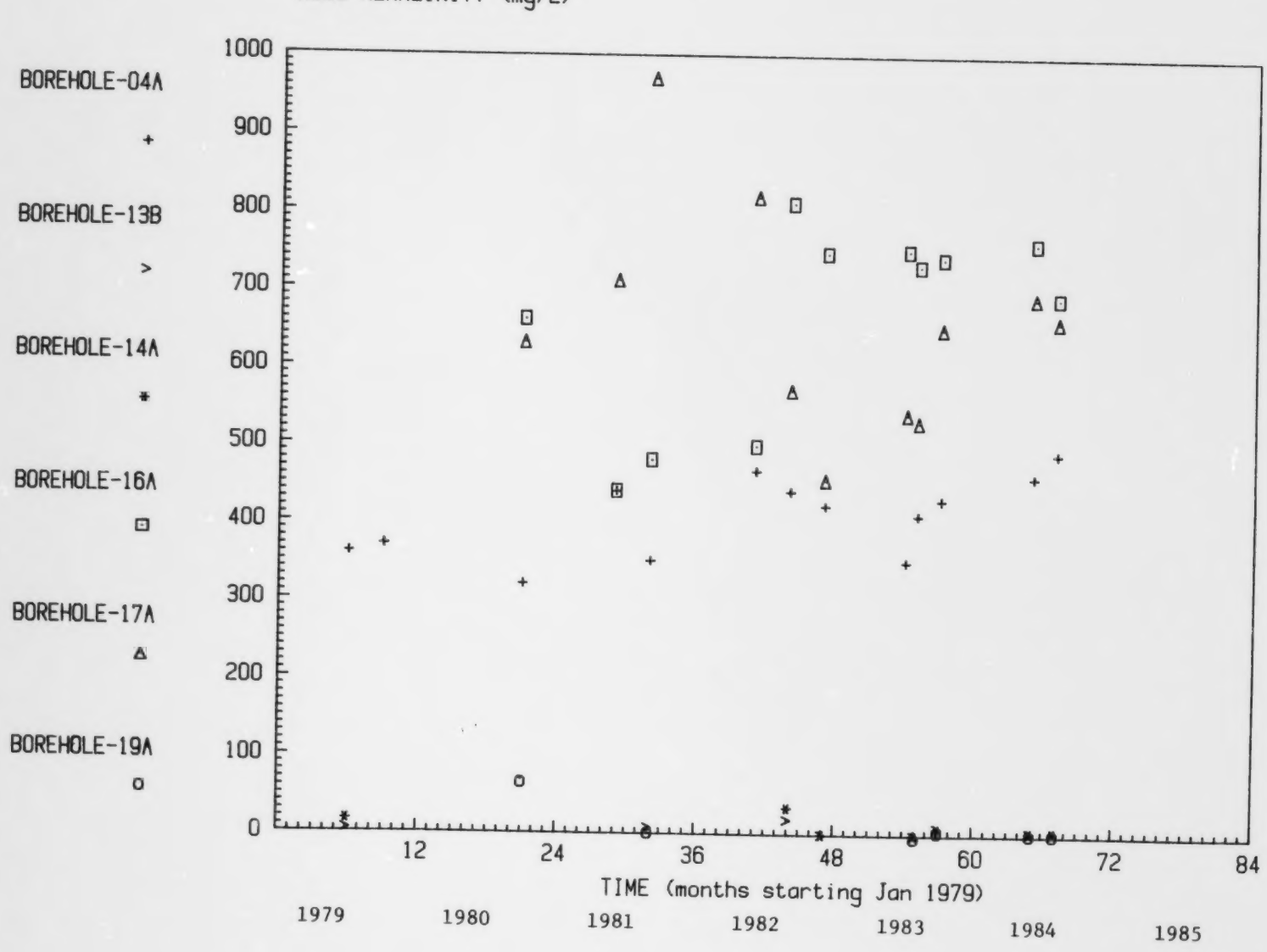


FIGURE 9

TBTGS FUEL - SELECTED BOREHOLES

ACIDITY 8.3 vs TIME

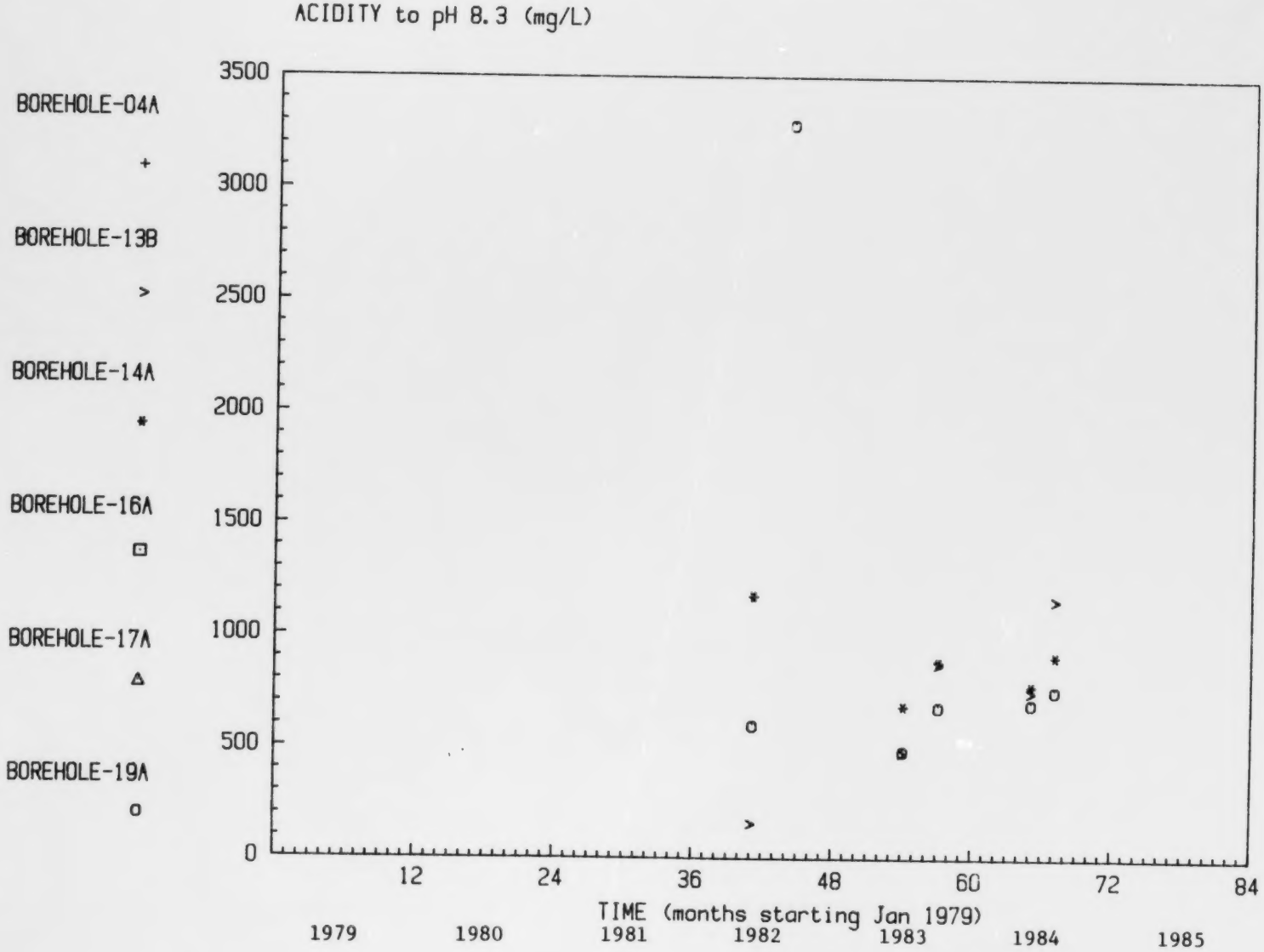


FIGURE 10

TBTGS FUEL - SELECTED BOREHOLES

CONDUCTIVITY (Lab) vs TIME

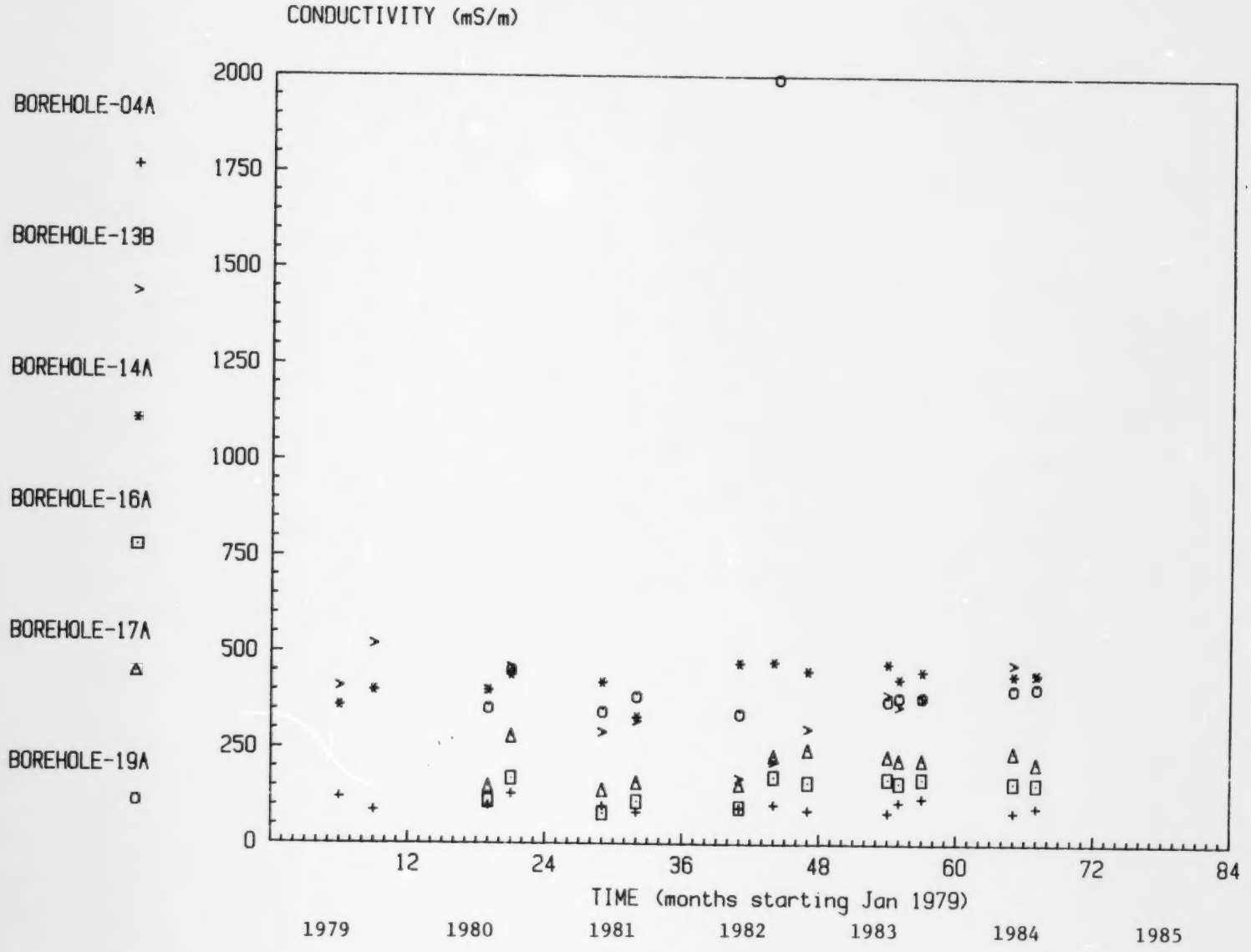


FIGURE 11

TBTGS FUEL - SELECTED BOREHOLES

IRON vs TIME

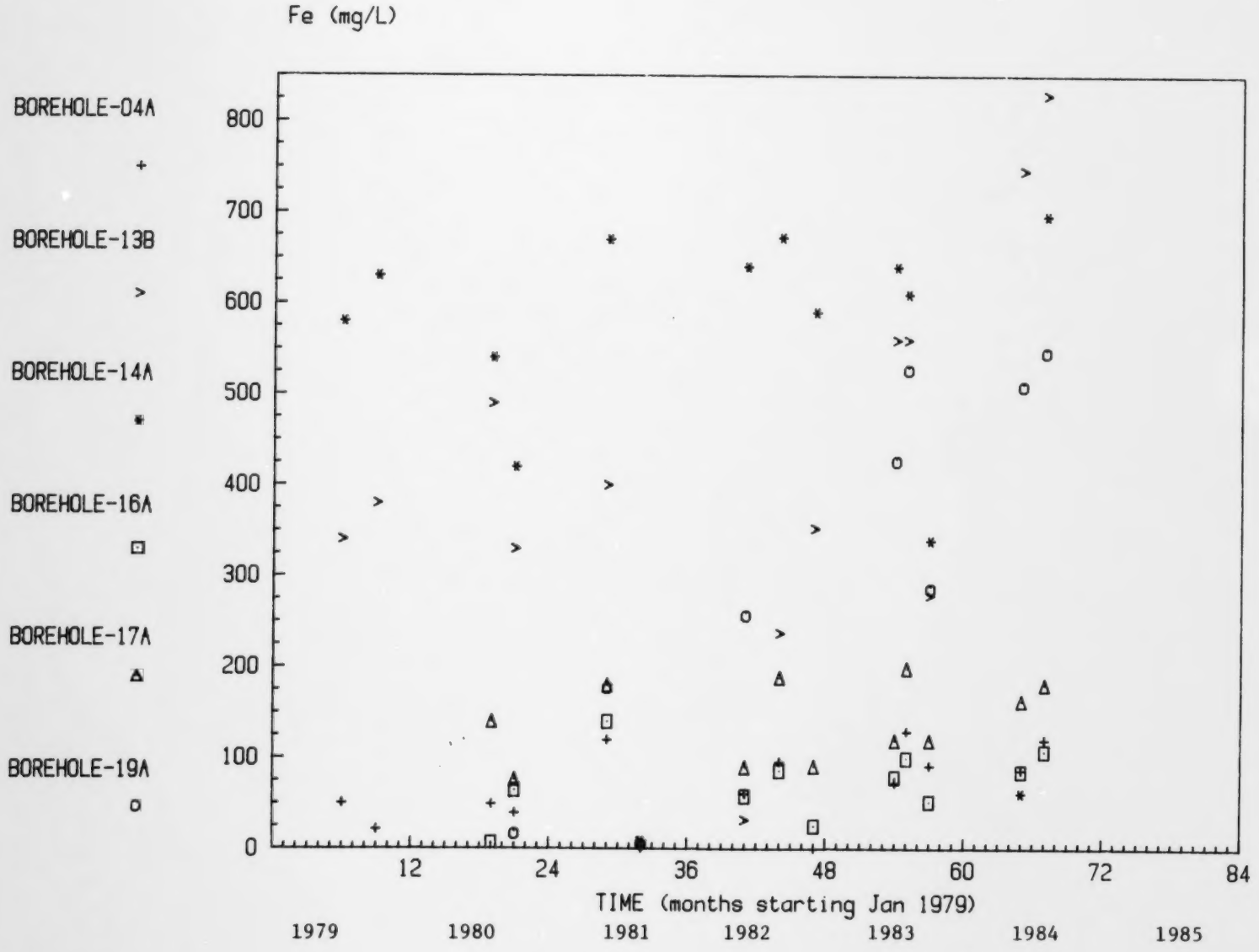
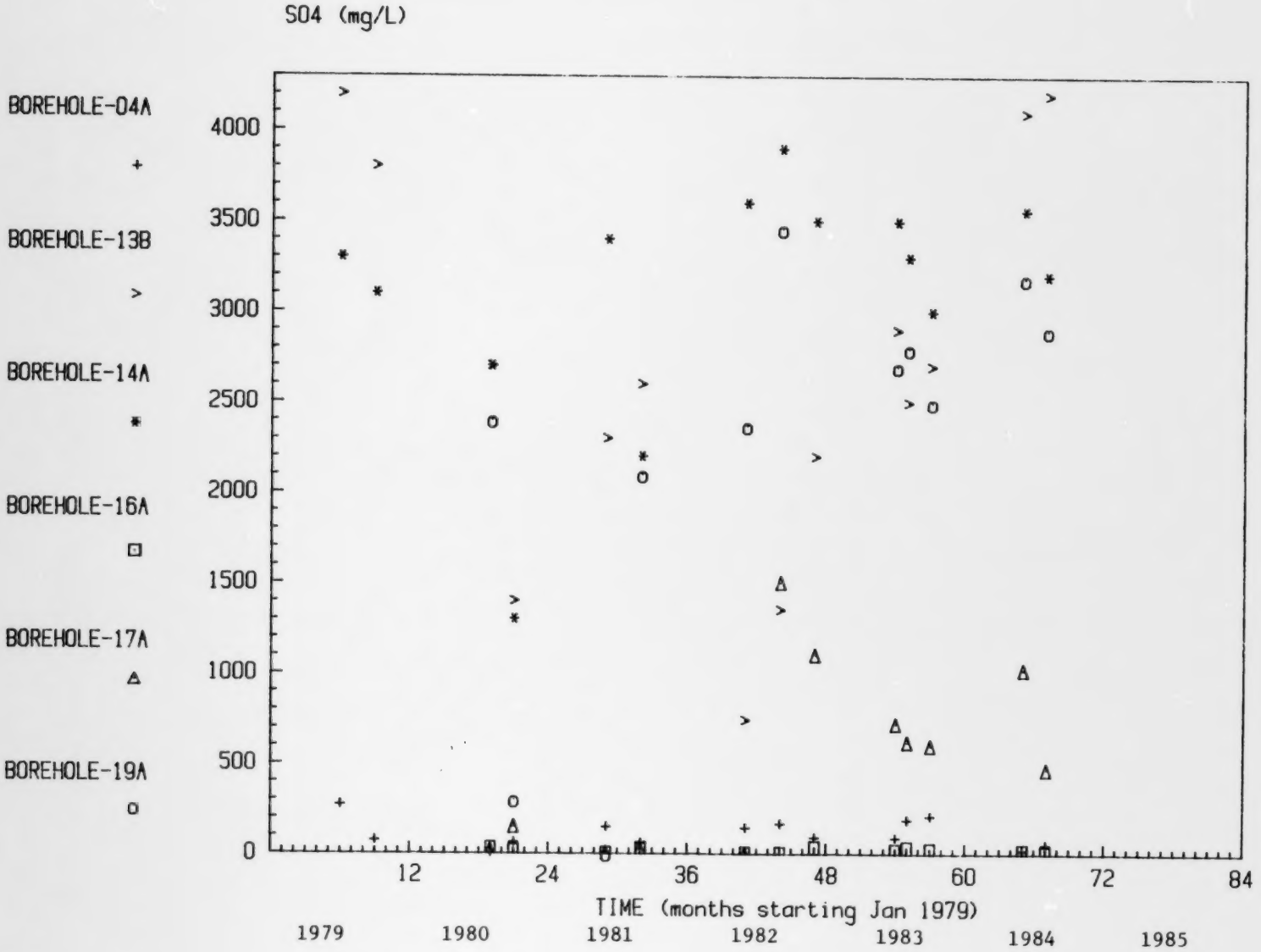


FIGURE 12

TBTGS FUEL - SELECTED BOREHOLES

SULPHATE vs TIME



lignite coal pile.

Careful consideration of the plots of all analytes confirms the finding that there are no significant temporal trends within the particular groups of piezometers.

STATISTICAL ANALYSIS

The Statistics and Reliability Unit of Operations Research was contracted to perform an analysis of variance (ANOVA) on the chemical analysis data from the fuel storage area at TBTGS. The results of that analysis are detailed in Ontario Hydro Research Division Report No 85-232-K, which is appended as Appendix D. The figures and tables referred to in this section are from Appendix D.

The purpose of this section is to:
1) provide a background to the statistical analysis
2) rationalize some of the steps which were required in the course of the statistical analysis
3) summarize the important statistical findings
4) relate the findings to a consistent set of observations and plans for the particular site.

1. Background

Before the ANOVA was initiated several variables were identified:
TYPE OF LABORATORY
LOCATION
STRATA
CHEMICAL SPECIES / ANALYTE
TIME

There were three laboratories involved in data collection since the beginning of the groundwater monitoring: London Monenco Ltd. (1979, preoperational phase); TBTGS laboratory (also designated as FIELD) and the Analytic Services Section laboratory at Research Division (LAB) were both involved after 1979.

When the groundwater monitoring project was initiated there was an arbitrary decision to divide the study into preoperational (before 1982) and postoperational. This division of the data set was not made as the resultant sets would have been too small to carry out appropriate statistics especially considering the other variables which had to be carried in the analysis. Besides, any trend which would justify the operational period divisions should have been apparent in the grouped data.

Each location has at least two piezometers at different depths

within different soil strata. This was incorporated into the initial site design in order to assess the depth of pollutant infiltration and the extent of migration. The strata were considered to be a significant variable for consideration in addition to the piezometer nest location around the stockpiling area.

Individual treatment of piezometers was not possible due to the severe restrictions placed upon a statistical analysis where the total number of observations for individual piezometers was not generally greater than 30 over the entire study. Individual trends in piezometer chemistry have been considered in separate time series plots for each analyte. Also, trends in piezometer chemistry have been implicitly incorporated into the overall analysis.

Time was considered the most important variable as the purpose of groundwater monitoring was to assess the changes in groundwater quality with time; in effect, to measure the influence of the presence of the deposited waste material on water quality.

There was a large number of values in the data set which were at analytical detection limits and which were reported as 'less than' values. These values were removed from the set in order to permit a more meaningful analysis. It must be kept in mind that the data set has been arbitrarily truncated and a consequent bias has been introduced. However, the bias is a conservative one, in that the average concentrations reported are higher. This favors environmental controls and limitations on the concentrations of all species. A tabulation of the analytes which have significant numbers of detection limit observations is shown in the the summary statistics (Table II, in Appendix D). In the course of the analysis it became clear that there were a number of arbitrary methods for dealing with large numbers of detection limit observations and the most conservative method seemed to be to ignore them in favor of higher values. An alternative would have been to assign the value of the detection limit as the actual value but even within one analyte these detection limit values varied considerably from date to date.

Another important variable for the data analysis was the frequency of sampling and the number of analyses performed in the two Ontario Hydro laboratories. Analyses were performed about 6 times a year on a limited set of analytes, at TBTGS and more thorough analyses were completed at the LAB, twice per year. This was not explicitly dealt with but the effect of various frequencies of analysis precluded a proper time series analysis (by month) for many analytes.

2. Trends in 'Indicator' Ions -- Fe and SO_4

Due to their high relative abundances in coal pile drainage Fe and SO_4 were chosen as indicators of leachate production. The temporal trends in these ions are interesting in that they are basically indeterminate and they seem to indicate the levels of expected variability in the site.

3. ANOVA Results and Discussion

The primary conclusions of the statistical study require some analysis which will rationalize them in terms of reasonable chemistry, site dynamics and natural variability.

a) **Piezometer location is significant in the majority of cases.** Much of the variance in the data set can be explained by the difference in piezometer locations. Those piezometers near the bituminous coal pile invariably had acidic waters and those further away showed natural variations in water chemistry.

b) **Strata is significant in less than one half of the species though some significant interactions warrant caution in accepting this solution for some species.**
It is expected that there would be a strong coupling of piezometers within a particular nest (dependent upon strata permeabilities) and the fact that this does not happen to the expected degree indicates substantial natural site variations as well as greater near-surface infiltration of the coal pile drainage.

c) **Testing site had a significant influence for the majority of species.**
The fact that 3 laboratories were involved in analyses contributed to the variance within the data set. Even when LMC data was deleted, there was a difference between the FIELD and LAB sets. There could be no further separation or deletion of data as the number of observations would have been reduced too significantly in some cases to warrant any further analysis.

d) **Date was significant for almost all species.**
The statistics leave no doubt that date is an important variable and that the mean values for analytes for each date were indeed different. However, it is the trend in year which is of importance in determining whether any change in the site has occurred. An analysis of the trend in the means of analytes by year shows **no intelligible overall trend.** This is due to the fact that there are only yearly fluctuations in the chemistries of piezometers which remain primarily within the same group (acidic or natural).

4. Conclusions

The conclusions which must be drawn from this are:

- the bituminous coal pile has caused acidification of groundwater in its immediate locale but the pH levels have not changed significantly over time

- with the available data, there is no statistically significant difference between the preoperational and postoperational periods

- the variations in analyte concentrations in the groundwater from nonacidic piezometers as a function of time reflect the natural variations which can be attributed to variations in site hydrogeochemistry

5. Predictive Values

Table II, in Appendix D, of summary statistics, provides an effective means to detect outliers. Early detection of outliers is necessary in order to:
-implement resampling at the site
-provide a check on analytical accuracy
-provide first indications of changes in site chemistry (of primary importance)

It is more effective to individually (manually) determine the cause of outlying values because of the complexity of the site characteristics and other potential errors which can occur. A purely statistical and automatic procedure of outlier flagging is not necessary at this time given the potential expense involved in system development as well as the reduced level of commitment to the overall project.

GENERAL COMMENTS

Recent plans indicate that the bituminous coal storage area will no longer be used /8/ and the area is being grassed over. It is expected that this will result in a significant change in groundwater quality in the immediate vicinity and the piezometers which have chronically had acidic waters should begin to return to a more normal chemistry. This, in turn, will affect any group statistics to be performed in the future and appropriate caution should be exercised in such analyses.

Because many of the analytes determined previously, such as silver, cadmium, mercury, zinc and other trace metals, were consistently at or below their detection limits, it appears

reasonable to discontinue their determination and to continue to monitor water quality in the area by less extensive analyses that can be conducted at TBTGS on fresh samples.

RECOMMENDATIONS

1. Consideration should be given to reducing the number of analytes to be tested in each analysis and to resolving the discrepency between analyses at the two laboratories. This could be done by analyzing samples only at TBTGS and determining only pH, conductivity, alkalinity, acidity (to pH 8.3), chloride, sulphate, calcium, magnesium, sodium, potassium, iron, manganese and boron.

2. The use of Piper diagrams should be continued to identify outliers in major ion chemistry.

3. A statistical reassessment should be performed only when the data set has increased significantly in size (5 years hence would be appropriate).

Reviewed by:

D. Dodd
Section Head
Environmental and Inorganic Research Section

Prepared by:

J. Complak
Chemist
Environmental and Inorganic Research Section

D.R. Chartier
Research Chemist
Environmental and Inorganic Research Section

Approved by:

O.A. Kupcis
Manager
Chemical Research Department

JC/DRC:eb/lt/jb

REFERENCES

1. London Monenco Consultants Ltd. Groundwater Monitoring Study, Coal Storage Area, Ontario Hydro, Thunder Bay Generating Station Extension, February 1980, Baseline Report.

2. Complak, J., "Fuel Storage Area Groundwater Monitoring Program - 1980, Thunder Bay TGS Extension," Ontario Hydro Research Division Report No 82-9-K, June 4, 1982.

3. Complak, J., "Pre-Operational Fuel Storage Area Groundwater Quality Studies - 1979-1981, Thunder Bay TGS Extension", Ontario Hydro Research Division Report No 83-130-K, August 11, 1983.

4. Complak, J., "Post-Operational Fuel Storage Area Groundwater Quality Studies - 1982, Thunder Bay TGS Extension", Ontario Hydro Research Division Report No 83-442-K, December 22, 1983.

5. Complak, J., "Post-Operational Fuel Storage Area Groundwater Quality - 1983, Thunder Bay TGS Extension", Ontario Hydro Research Division Report No 84-103-K, July 12, 1984.

6. American Public Health Association, American Water Works Association and Water Pollution Control Federation. Standard Methods for the Examination of Water and Wastewater. Washington: Publication Office, American Public Health Association Inc., 1975.

7. Chartier, D. R., "Lignite Coal Pile Drainage", Ontario Hydro Research Division Report No 81-22-K, March 16, 1981.

8. Chubbuck, D. Personal communication, June 17, 1985.

APPENDIX A

TBTGS FUEL AREA GROUNDWATER AND LAKE* LEVELS
1979 - 1984

* (Lake Superior levels were obtained from Marine Environmental Data, Services Branch, Fisheries and Oceans, Ottawa)

TABLE II

FUEL STORAGE AREA - GROUNDWATER MONITORING PROGRAM - 1981
THUNDER BAY TGS EXTENSION

RELATIVE PIEZOMETER AND LAKE WATER LEVELS - 1981
(Relative to Average Shoreline Level of 182.88 m)

Piezometer Identification		Relative Water Levels in Piezometers (m)						
		Dates Measurements Were Taken						
		June 14/79	Sept. 27/79	Apr. 27/81	May 8/81	July 2/81	Aug. 25/81	Sept. 4/81
P79	1A	1.36	1.28	*1.57 (F)	*1.28	*1.31	*1.05	*1.11
	1B	Dry	Dry	*1.43	*1.38	*1.29	*0.97	*1.11
P79	2A	1.68	1.17	*N.A.	*1.90	*N.A.	*0.91	*1.09
	2B	1.68	1.18	*N.A.	*1.85	*N.A.	*0.91	*1.09
	2C	1.76	1.18	*N.A.	*1.79	*N.A.	*0.92	*1.09
P79	3A	0.62	0.59	*N.A.	*N.A.	*Dry	*N.A.	*N.A.
	3B	0.61	0.61	*N.A.	*N.A.	*Dry	*N.A.	*N.A.
P79	4A	0.55	0.61	0.56	0.58	0.60	0.39	0.40
	4B	0.55	0.63	0.47	0.52	0.59	0.37	0.40
	4C	0.55	0.65	0.49	0.48	0.57	0.36	0.37
P79	5A	0.46	0.55	0.10	0.11	0.34	0.24	0.15
	5B	0.54	0.54	0.14	0.20	0.34	0.24	0.18
	5C	0.54	0.54	0.14	0.28	0.33	0.20	0.19
P79	6A	0.97	0.55	0.54	0.20	0.35	0.23	0.53
	6B	0.55	0.54	0.13	0.23	0.36	0.23	0.22
	6C	0.55	0.55	-0.30	0.18	0.31	0.21	-0.27
P79	7A	0.64	0.66	0.63	0.57	1.73	0.35	-0.57
	7B	0.65	0.68	0.91	0.53	0.72	0.34	-0.03
	7C	0.69	0.65	0.00	0.56	0.74	0.34	-0.02
P79	8A	0.61	0.51	0.67	0.42	0.72	-0.15	-0.28
	8B	0.38	0.50	0.59	0.45	0.75	-0.15	-0.25
	8C	0.43	0.50	0.31	0.43	0.71	-0.16	-0.19
P79	9A	0.54	0.48	0.73	0.49	0.51	0.38	0.44
	9B	0.55	0.48	0.60	0.43	0.49	0.39	0.43
	9C	0.54	0.48	0.93	0.76	1.49	0.69	1.75
P79	10A	0.00	0.00	*1.00 (F)	*Dry	*Dry	*N.A.	*N.A.
	10B	0.10	0.78	*1.18 (F)	*Dry	*Dry	*N.A.	*N.A.
	10C	0.00	0.76	*1.17 (F)	*Dry	*Dry	*N.A.	*N.A.
P79	11A	0.51	1.03	*1.37	*1.23	*1.09	*0.94	*1.02
	11B	0.50	1.05	*1.38	*1.24	*1.09	*0.93	*1.05
P79	12A	0.53	0.50	0.57	0.95	0.34	0.51	0.54
	12B	0.53	0.49	0.47	0.43	0.58	0.46	0.44
	12C	0.53	0.50	0.36	0.45	0.32	0.44	0.38
P79	13A	0.53	0.50	0.34	0.39	0.48	0.48	0.42
	13B	0.54	0.51	0.42	0.47	0.57	0.47	0.47
	13C	0.56	0.52	0.55	0.57	0.65	0.58	0.59
P79	14A	0.51	0.47	0.25	0.33	0.43	0.34	0.38
	14B	0.49	0.47	0.32	0.36	0.49	0.40	0.43
	14C	0.49	0.47	0.37	0.41	0.51	0.34	0.47
P80	15A			0.31	0.43	0.43	0.68	0.39
	15B			0.41	0.51	0.86	0.50	0.65
P80	16A			0.54	0.73	1.11	0.60	0.54
	16B			0.70	0.91	1.26	0.76	0.70
P80	17A			-0.13	1.00	0.67	0.05	-0.13
	17B			0.75	1.99	1.16	0.86	0.81
P80	18A			0.33	0.41	0.50	0.41	0.42
	18B			0.32	0.38	0.47	0.38	0.42
P80	19A			0.25	0.41	0.43	0.35	0.90
	19B			0.54	0.31	0.46	0.40	0.77
P80	20A			0.90	1.33	1.36	0.80	
	20B			0.95 (F)	1.24	1.33	0.78	
Lake Levels (1)		0.40	0.40	0.05	0.13	0.25	0.23	0.16

F = Frozen

N.A. = Not Available

* These values are based on the 1979 Piezometer Reference Levels.
The remaining values are based on July 16, 1981 Piezometer Reference Levels.

**Piezometers P80-15A to 20B are current TBTGS designations for piezometers originally designated, by Civil Research, as P80-1A to 6B.

(1) Marine Environmental Data, Services Branch, Fisheries and Oceans, Ottawa. (See Appendix for detailed data)

TABLE I:

FUEL STORAGE AREA - GROUNDWATER MONITORING PROGRAM - 1982
THUNDER BAY TGS EXTENSION

RELATIVE PIEZOMETER AND LAKE WATER LEVELS - 1982
(Relative to Average Shoreline Level of 182.88 m)

Piezometer Identification	Relative Water Levels in Piezometers (m)			
	Dates Measurements Were Taken			
	May 14/82	Aug. 23/82	Oct. 29/82	Nov. 9/82
P79 1A	1.22	1.28	1.29	1.27
P79 1B	1.28	1.13	1.27	1.21
P79 2A	2.11	1.75	-	-
P79 2B	2.09	1.75	-	-
P79 2C	2.09	1.78	-	-
P79 3A	0.68	0.55	0.57	0.56
P79 3B	0.73	0.65	0.66	0.64
P79 4A	0.46	0.57	0.69	0.58
P79 4B	0.51	0.56	0.70	0.59
P79 4C	0.51	0.56	0.69	0.60
P79 5A	0.17	0.33	0.59	0.46
P79 5B	0.18	0.42	0.60	0.49
P79 5C	0.18	0.54	0.61	0.35
P79 6A	0.23	0.43	0.60	0.43
P79 6B	0.23	0.41	0.58	0.49
P79 6C	0.20	0.40	0.57	0.46
P79 7A	-	0.16	0.09	0.00
P79 7B	-	0.15	0.10	-0.06
P79 7C	-	0.18	0.13	-0.24
P79 8A	0.24	0.15	0.10	-0.15
P79 8B	0.31	0.15	0.11	-0.11
P79 8C	0.38	0.18	0.18	-0.03
P79 9A	0.45	0.40	0.50	0.45
P79 9B	0.40	0.47	0.57	0.43
P79 9C	0.37	0.39	0.50	0.45
P79 10A	-	-	-	-
P79 10B	-	-	-	-
P79 10C	-	-	-	-
P79 11A	1.26	1.22	1.16	1.13
P79 11B	1.21	1.21	1.15	1.13
P79 12A	0.38	0.43	0.54	0.46
P79 12B	0.41	0.41	0.54	0.55
P79 12C	0.52	0.32	0.55	0.46
P79 13A	0.42	0.53	0.58	0.57
P79 13B	0.56	0.48	0.56	0.23
P79 13C	0.66	0.44	0.53	0.53
P79 14A	0.41	0.44	0.54	0.44
P79 14B	0.40	0.45	0.53	0.45
P79 14C	0.40	0.45	0.53	0.46
P80 15A	0.37	0.70	0.94	0.75
P80 15B	0.49	1.14	0.48	1.34
P80 16A	0.57	0.92	0.21	0.93
P80 16B	0.70	0.92	0.20	0.93
P80 17A	0.03	0.59	0.83	0.60
P80 17B	0.82	0.69	0.99	0.65
P80 18A	0.37	0.44	0.53	0.49
P80 18B	0.36	0.41	0.51	0.46
P80 19A	0.03	0.40	-0.04	0.46
P80 19B	0.66	0.44	0.53	0.49
P80 20A	-	-	-	-
P80 20B	-	-	-	-
Lake Levels (1)	0.09	0.30	0.38	0.40

(1) Marine Environmental Data, Services Branch, Fisheries and Oceans, Ottawa. (See Appendix for detailed data)

TABLE II

FUEL STORAGE AREA - GROUNDWATER QUALITY STUDIES - 1983
THUNDER BAY TGS EXTENSION

RELATIVE PIEZOMETER AND LAKE WATER LEVELS - 1983
(Relative to Average Shoreline Level of 182.88 m)

Piezometer Identification	Relative Water Levels in Piezometers (m)					
	Dates Measurements Taken					
	May 5, 1983	May 31, 1983	June 24, 1983	July 26, 1983	Sept 20, 1983	Oct 28, 1983
P79 1A	1.33	1.33	1.22	1.11	1.18	1.24
P79 1B	1.24	1.30	1.20	1.10	1.17	1.24
P79 2A	-	-	-	-	-	--
P79 2B	-	-	-	-	-	--
P79 2C	-	-	-	-	-	--
P79 3A	0.83	-	0.68	0.51	0.60	0.69
P79 3B	0.85	-	0.69	0.53	0.61	0.72
P79 4A	0.80	0.54	0.48	0.46	0.44	0.53
P79 4B	0.49	-	0.48	0.45	0.46	0.54
P79 4C	0.49	-	0.49	0.45	0.44	0.53
P79 5A	0.31	-	0.41	0.42	0.40	0.49
P79 5B	0.37	-	0.42	0.43	0.41	0.45
P79 5C	0.37	0.40	0.41	0.42	0.43	0.44
P79 6A	0.29	-	0.38	0.40	0.38	--
P79 6B	0.33	0.39	0.40	0.41	0.40	0.41
P79 6C	0.31	0.46	0.37	0.39	0.38	--
P79 7A	-0.12	-	-0.15	-0.17	-0.14	0.09
P79 7B	-0.09	-0.13	-0.11	-0.13	-0.04	0.06
P79 7C	-0.04	-	-0.04	-0.07	0.01	0.10
P79 8A	-0.12	-	-0.13	-0.13	-0.04	0.04
P79 8B	-0.12	-0.13	-0.14	-0.11	-0.03	0.03
P79 8C	-0.04	-	-0.02	0.01	0.03	0.10
P79 9A	0.26	-	0.39	0.33	0.32	0.36
P79 9B	0.21	-	0.40	0.35	0.34	0.37
P79 9C	0.27	-	0.40	0.36	0.34	0.36
P79 10A	-	-	-	-	-	--
P79 10B	-	-	-	-	-	--
P79 10C	-	-	-	-	-	--
P79 11A	1.15	-	1.04	0.97	1.15	1.16
P79 11B	1.09	-	1.05	0.97	1.16	1.15
P79 12A	0.30	-	0.40	0.22	0.37	0.39
P79 12B	0.30	-	0.40	0.38	0.37	0.40
P79 12C	0.29	0.40	0.40	0.37	0.37	0.39
P79 13A	0.34	-	0.41	0.38	0.41	0.45
P79 13B	0.32	0.41	0.38	0.37	0.41	0.42
P79 13C	0.29	0.39	0.35	0.36	0.37	0.41
P79 14A	0.30	0.35	0.35	0.36	0.38	0.39
P79 14B	0.30	0.37	0.35	0.38	0.38	0.40
P79 14C	0.30	0.37	0.36	0.38	0.40	0.40
P80 15A	0.57	0.66	0.62	0.58	0.57	0.69
P80 15B	0.90	1.07	1.05	0.91	0.59	1.30
P80 16A	0.73	0.84	0.76	0.69	0.69	--
P80 16B	0.73	0.86	0.76	0.72	0.69	--
P80 17A	0.42	0.53	0.55	0.52	0.49	0.57
P80 17B	0.39	0.69	0.73	0.48	0.52	0.79
P80 18A	0.25	0.38	0.37	0.44	0.39	0.38
P80 18B	0.30	0.38	0.37	0.39	0.39	0.40
P80 19A	0.29	0.33	0.34	0.39	0.36	0.37
P80 19B	0.29	0.36	0.36	0.81	0.36	0.39
P80 20A	-	-	-	-	-	--
P80 20B	-	-	-	-	-	--
Lake Levels	-	0.25	0.34	0.38	0.34	0.38

(1) Marine Environmental Data, Services Branch, Fisheries and Oceans, Ottawa. (See Appendix for detailed data)

TABLE III

FUEL STORAGE AREA - GROUNDWATER QUALITY - 1984
THUNDER BAY TGS EXTENSION

RELATIVE PIEZOMETER AND LAKE WATER LEVELS - 1984
(Relative to Average Shoreline Level of 182.88 m)

Piezometer Identification	Relative Water Levels in Piezometers (m)			
	Dates Measurements Taken			
	May 14, 1984	July 6, 1984	July 19, 1984	Oct. 26, 1984
P79 1A	1.33	1.23	1.21	1.17
P79 1B	1.32	1.23	-	1.16
P79 2A	-	-	-	-
P79 2B	-	-	-	-
P79 2C	-	-	-	-
P79 3A	0.83	0.70	0.68	0.66
P79 3B	0.82	0.72	-	0.67
P79 4A	0.45	0.57	0.53	0.95
P79 4B	0.45	0.58	-	0.48
P79 4C	0.43	0.57	-	0.93
P79 5A	0.32	0.52	-	0.41
P79 5B	0.33	0.54	-	0.41
P79 5C	0.35	0.54	0.51	0.41
P79 6A	0.25	0.56	-	0.38
P79 6B	0.27	0.51	0.50	0.39
P79 6C	0.23	0.47	0.45	0.35
P79 7A	-0.12	0.17	-	0.07
P79 7B	-0.12	0.19	-0.02	0.06
P79 7C	-0.05	0.22	-	0.09
P79 8A	-0.23	0.14	-	0.06
P79 8B	-0.21	0.14	-0.02	0.05
P79 8C	-0.11	0.21	-	0.10
P79 9A	0.25	0.41	-	0.34
P79 9B	0.25	0.41	-	0.35
P79 9C	0.27	0.42	-	0.36
P79 10A	-	-	-	-
P79 10B	-	-	-	-
P79 10C	-	-	-	-
P79 11A	0.67	1.13	-	1.02
P79 11B	0.71*	1.13	-	1.02
P79 12A	0.28	0.44	-	0.37
P79 12B	0.29	0.44	-	0.37
P79 12C	0.26	0.43	0.41	0.36
P79 13A	0.38	0.49	-	0.20
P79 13B	0.39	0.47	0.45	0.21
P79 13C	0.33	0.43	0.43	0.20
P79 14A	0.30	0.42	0.43	0.38
P79 14B	0.29	0.42	0.43	0.38
P79 14C	0.28	0.42	0.42	0.38
P80 15A	0.55	0.82	0.73	0.54
P80 15B	1.18	1.41	1.18	0.90
P80 16A	0.70**	-	-	0.73
P80 16B	0.66	0.98	0.85	0.72
P80 17A	0.48	0.85	0.64	0.49
P80 17B	0.28	1.12	1.02	0.67
P80 18A	0.42	0.43	0.45	0.39
P80 18B	0.31	0.44	0.44	0.39
P80 19A	0.29	0.40	0.40	0.34
P80 19B	0.31	0.42	0.44	0.37
P80 20A	-	-	-	-
P80 20B	-	-	-	-
Lake Level (1)	0.23	0.39	0.39	0.35

(1) Relative average monthly lake levels (relative to 182.88 m average lake level) for Station 10050, Thunder Bay Harbour. Data obtained from Marine Environmental Data, Services Branch, Fisheries and Oceans, Ottawa.

* Piezometer cap missing
** Piezometer top broken

APPENDIX B

TOTAL PRECIPITATION
1979 - 1984
THUNDERBAY A (AIRPORT)

ENVIRONMENT CANADA

FROM
(ATMOSPHERIC ENVIRONMENT SERVICE)
CANADIAN CLIMATE CENTRE
DOWNSVIEW, ONTARIO

ANNUAL METEOROLOGICAL SUMMARY
SOMMAIRE MÉTÉOROLOGIQUE ANNUEL

STATION THUNDER BAY "A" ONTARIO YEAR/ANNÉE: 1979

METEOROLOGICAL DATA FOR THE YEAR / DONNÉES MÉTÉOROLOGIQUE POUR L'ANNÉE

TOTAL DAILY PRECIPITATION OF RAIN & SNOW / PRECIPITATION TOTALE DE PLUIE ET DE NEIGE

DATE	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOÛT	SEPT SEP	OCT OCT	NOV NOV	DEC DEC
1		TR	TR			1.2			11.9	6.7	0.2	
2	TR	0.4	14.4		0.3				2.0	1.0	TR	
3	TR	0.2	11.6			TR		0.2	TR	8.5	TR	TR
4		TR	0.4		TR	3.2	TR	4.4		0.2	TR	6.6
5		0.8		TR					1.2			0.2
6	TR	3.9			5.4	9.4		0.2	0.2	TR	TR	0.4
7		0.6	TR		8.0				0.3		3.6	
8	0.5	TR	1.2	12.2	6.8		1.4			1.8	0.6	TR
9		TR	2.3		22.2	7.6	TR	1.8	2.0	TR	TR	3.5
10		TR	TR		34.4	10.4			1.0	TR	TR	8.0
11	TR	0.6	1.0		TR				15.4	7.0	0.8	2.0
12	TR	2.0	3.9	20.8				9.9		0.4	TR	TR
13		3.6	0.2	3.6	TR			2.4	0.4		0.8	0.5
14		7.9	1.8		TR	0.2			0.2	TR	0.2	TR
15		4.1				2.8	TR		0.4		TR	TR
16	0.4	TR				TR				0.4		
17	5.0		0.2		4.6							
18	0.2	TR	6.2		0.8		4.2			15.9		2.7
19	1.0		8.4	0.8	TR		TR		7.2	10.6	2.2	
20	5.1		TR	6.4	1.0	11.1			1.5	TR		
21	3.2	10.9	TR	TR		1.8	14.2			0.4		
22	TR	9.9	25.8	2.4	2.4			10.5		13.8	TR	TR
23	0.4	11.6	3.2	6.0			0.2	6.3	TR	2.2	4.8	TR
24	TR			1.8			8.4	0.6		TR	TR	TR
25		TR		1.4		3.1	TR	TR		TR		
26		TR		TR			0.2	0.8		TR	0.9	
27	0.4		TR	TR					3.0	7.4	TR	
28	TR	4.8	10.6			0.4		6.8	TR	TR	1.8	
29						1.2		7.2	0.4	TR	TR	
30	TR		11.7		0.4	TR	9.2		0.4		TR	
31	TR				10.2			17.0		14.8		
Total	16.2	61.3	102.9	55.4	96.5	52.4	37.8	68.1	47.5	91.1	15.9	23.9

ANNUAL METEOROLOGICAL SUMMARY
SOMMAIRE MÉTÉOROLOGIQUE ANNUEL

for/pour THUNDER BAY "A" ONTARIO YEAR/ANNÉE: 1980

METEOROLOGICAL DATA FOR THE YEAR / DONNÉES MÉTÉOROLOGIQUE POUR L'ANNÉE												
TOTAL DAILY PRECIPITATION OF RAIN & SNOW / PRECIPITATION TOTALE DE PLUIE ET NEIGE												
DATE	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOÛT	SEPT SEP	OCT OCT	NOV NOV	DEC DEC
1						6.8	2.6	0.2	5.8	0.4		TR
2	TR								0.2			
3	TR		TR						4.2		0.2	7.8
4	0.5	0.4	TR				16.1	6.2	6.2			TR
5	1.4	0.4			TR	TR			TR		TR	2.0
6	24.5	TR		2.4	0.8	TR	0.6		0.8			0.6
7	1.2			1.8	TR	5.0	2.6		0.2			1.8
8	TR	TR		2.0	0.4	0.7		1.8	30.6		19.4	0.4
9	TR	TR	0.2	11.3				TR			0.6	1.0
10	6.4	1.0	2.2	TR	11.4		TR	0.2		6.8	TR	
11	12.1	0.3		TR	TR			3.0		0.4		TR
12	2.3	TR	8.2	TR	0.2	3.1	TR	2.6	29.8		7.8	8.6
13	0.4	TR	7.4	TR				22.3	44.7		0.4	TR
14		TR			TR	3.8	10.8	TR		TR	TR	
15	6.8	TR	TR	TR					TR		TR	0.8
16			8.9				40.5		TR	7.6	TR	1.8
17	TR		0.2	TR		TR		5.5	3.8	5.2	TR	7.0
18	TR		TR				2.2	TR	6.0			TR
19	TR	4.2	TR	0.2				1.9	33.9	TR		
20		TR	3.5				1.2	3.0		1.2	5.6	
21		TR				TR	38.8	0.8		TR		TR
22	TR	1.4					1.9		0.7	TR		2.3
23		1.0	1.8	TR		8.2		0.6		13.1	0.2	TR
24	0.4	0.4		1.9			0.6	15.0	4.4	28.6	TR	
25	TR			0.7						0.2		1.2
26	TR	2.8		0.2	9.6				0.8	TR		TR
27	1.2		4.5		TR	0.8	2.2	1.8		TR	0.6	0.8
28	TR					25.9	7.4	TR			5.5	TR
29	TR					4.4		34.8	1.8		0.4	TR
30					10.4	TR	0.2	24.3	1.0		TR	10.0
31										TR		1.4
Total	57.2	11.9	36.9	20.5	32.8	58.7	237.7	124	174.9	63.5	40.7	47.5

TR = Less than 0.2 mm

ANNUAL METEOROLOGICAL SUMMARY
SOMMAIRE MÉTÉOROLOGIQUE ANNUEL

for/pour THUNDER BAY "A" ONTARIO YEAR/ANNÉE: 1980

METEOROLOGICAL DATA FOR THE YEAR / DONNÉES MÉTÉOROLOGIQUE POUR L'ANNÉE

TOTAL DAILY PRECIPITATION OF RAIN & SNOW / PRECIPITATION TOTALE DE PLUIE ET NEIGE

DATE	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOÛT	SEPT SEP	OCT OCT	NOV NOV	DEC DEC
1						6.8	2.6	0.2	5.8	0.4		TR
2	TR								0.2			
3	TR		TR						4.2		0.2	7.8
4	0.5	0.4	TR				16.1	6.2	6.2			TR
5	1.4	0.4			TR	TR			TR		TR	2.0
6	24.5	TR		2.4	0.8	TR	0.6		0.8			0.6
7	1.2			1.8	TR	5.0	2.6		0.2			1.8
8	TR	TR		2.0	0.4	0.7		1.8	30.6		19.4	0.4
9	TR	TR	0.2	11.3				TR			0.6	1.0
10	6.4	1.0	2.2	TR	11.4		TR	0.2		6.8	TR	
11	12.1	0.3		TR	TR			3.0		0.4		TR
12	2.3	TR	8.2	TR	0.2	3.1	TR	2.6	29.8		7.8	8.6
13	0.4	TR	7.4	TR				22.3	44.7		0.4	TR
14		TR			TR	3.8	10.8	TR		TR	TR	
15	6.8	TR	TR	TR					TR		TR	0.8
16			8.9				40.5		TR	7.6	TR	1.8
17	TR		0.2	TR		TR		5.5	3.8	5.2	TR	7.0
18	TR		TR				2.2	TR	6.0			TR
19	TR	4.2	TR	0.2				1.9	33.9	TR		
20		TR	3.5				1.2	3.0		1.2	5.6	
21		TR				TR	38.8	0.8		TR		TR
22	TR	1.4					1.9		0.7	TR		2.3
23		1.0	1.8	TR		8.2		0.6		13.1	0.2	TR
24	0.4	0.4		1.9			0.6	15.0	4.4	28.6	TR	
25	TR			0.7						0.2		1.2
26	TR	2.8		0.2	9.6				0.8	TR		TR
27	1.2		4.5		TR	0.8	2.2	1.8		TR	0.6	0.8
28	TR					25.9	7.4	TR			5.5	TR
29	TR					4.4		34.8	1.8		0.4	TR
30					10.4	TR	0.2	24.3	1.0		TR	10.0
31										TR		1.4
Total	57.2	11.9	36.9	20.5	32.8	58.7	127.7	124	174.9	63.5	40.7	47.5

TR = Less than 0.2 mm

ANNUAL METEOROLOGICAL SUMMARY
SOMMAIRE MÉTÉOROLOGIQUE ANNUEL

for/pour THUNDER BAY "A", ONTARIO YEAR/ANNÉE: 1981

METEOROLOGICAL DATA FOR THE YEAR / DONNÉES MÉTÉOROLOGIQUE POUR L'ANNÉE

TOTAL DAILY PRECIPITATION OF RAIN & SNOW / PRECIPITATION TOTALE DE PLUIE ET DE NEIGE

DATE	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOÛT	SEPT SEP	OCT OCT	NOV NOV	DEC DEC
1	TR	5.2	1.0	0.4		23.5		TR	0.3	21.1		1.1
2			TR	TR	15.8	16.3						0.2
3		TR	5.2	13.0	2.4	31.0	3.2	0.4				3.7
4			TR	5.0	1.0		TR	0.2		3.1		0.8
5	1.5	0.4	0.8		0.8	1.9				7.8	TR	TR
6	0.4	TR						3.6		1.2		TR
7		1.3	TR			10.6		10.3	13.6			TR
8	TR	TR			TR	0.8	0.3	1.9		0.5		TR
9	TR	TR	0.2		5.4	2.4		5.8			TR	TR
10		0.4	0.8	2.2		1.6		TR		1.6	0.6	
11	TR		TR			2.8			0.4	TR	TR	
12	TR		TR			0.9						0.8
13	0.2	1.2		10.7		8.5			0.4	16.4		TR
14	1.3	TR		TR		4.8		3.5		1.5		0.2
15	TR	0.4			TR				TR		0.2	TR
16	TR	1.4	TR	0.6			TR		TR		1.8	TR
17		3.8	TR	TR		4.6	3.2		TR	8.6		TR
18		3.1	TR			3.8	TR			0.6		TR
19			0.2	TR			TR			1.4	TR	
20	TR		TR			9.6	0.3			0.6	0.6	3.0
21		TR	TR	0.6		TR				TR	TR	1.8
22		30.5	TR	2.4	TR			TR		3.2		1.6
23		1.9		13.3	2.3	TR			0.2	TR		0.6
24		TR			23.3	23.6	0.4		1.3	2.2	0.3	
25		TR	TR		3.1		TR		0.2	0.6	5.0	0.2
26	1.2	TR	TR	0.6					9.4		14.1	4.0
27	TR	5.7		0.2					1.1		1.0	7.4
28	0.8	0.2	12.8		0.6	16.3	TR			TR	TR	
29	TR		1.8	0.4	4.8	7.2		2.0		1.0	TR	TR
30			1.6		TR				11.2			2.8
31	2.4		8.7				TR	57.9				2.0
Total	7.8	55.5	33.1	49.4	595	170.2	7.4	85.6	38.1	71.4	236	30.2

NOTE: TR = less than 0.2 mm

ANNUAL METEOROLOGICAL SUMMARY
SOMMAIRE MÉTÉOROLOGIQUE ANNUEL

for/pour THUNDER BAY "A", ONTARIO YEAR/ANNÉE: 1982

METEOROLOGICAL DATA FOR THE YEAR / DONNÉES MÉTÉOROLOGIQUE POUR L'ANNÉE

TOTAL DAILY PRECIPITATION OF RAIN & SNOW / PRECIPITATION TOTALE DE PLUIE ET DE NEIGE

DATE	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOÛT	SEPT SEP	OCT OCT	NOV NOV	DEC DEC
1		1.8	0.2	TR		1.0			4.0	TR		TR
2	25.0	0.2		14.1			0.4	3.8	4.1	8.6		2.2
3	1.2			12.0			16.8	28.0			8.9	0.4
4			TR	0.2	3.5				0.2	0.3	4.5	
5	4.4	TR			6.2		34.6	TR			TR	0.2
6		0.2	TR		5.5		44.5	1.2		36.1	TR	TR
7		TR				TR	29.2	3.6	0.2	20.8		
8	0.9		0.2				TR	3.4		TR	TR	TR
9	0.2		0.2		4.2	21.0	0.4	0.2		18.0		TR
10	0.9		9.6	0.4	16.8	1.0	4.2		1.8	21.0	12.1	TR
11	TR	TR	TR		1.2	1.2	2.2		TR	3.6	0.4	
12			17.7	3.4	0.6	TR	6.6		13.2	12.1	2.5	TR
13	TR	0.2	TR		19.6	4.8	19.6		0.8	TR	TR	0.2
14	1.3	1.2			2.0	14.8	1.0			TR		3.2
15	0.2			5.3	TR	TR	0.2			TR		TR
16	0.2		1.3	6.3	3.2	6.9	0.9		1.0			TR
17			TR	0.3	3.4	0.8	27.2		7.6	3.3		2.4
18	TR	TR	5.2		4.3			52.4	0.2	8.2		TR
19	6.6				TR	TR			2.8	0.7	1.8	0.2
20		TR	0.4			1.8				2.1	20.0	0.2
21	0.3		1.0			8.0	3.2	7.6			TR	3.0
22	7.2	3.2						6.6			2.2	0.4
23	7.9							1.0	7.6		TR	7.5
24			4.4			4.9		3.2	0.6		TR	
25			0.3					2.0				1.9
26	TR	TR					0.2			TR		
27	TR					7.1	0.8		1.4	TR		1.8
28	TR	4.6							1.8	3.1		19.4
29	1.8		0.4		3.8		8.3	4.3	2.8	3.5		TR
30	TR		22.9							0.2	TR	TR
31			1.0		2.8			9.0				0.2
Total	58.1	11.4	64.8	42	77.1	73.3	200.3	126.3	50.1	141.6	52.4	43.2

NOTE: TR = less than 0.2 mm

ANNUAL METEOROLOGICAL SUMMARY
SOMMAIRE MÉTÉOROLOGIQUE ANNUEL

for/pour THUNDER BAY "A", ONTARIO YEAR/ANNÉE: 1983

METEOROLOGICAL DATA FOR THE YEAR / DONNÉES MÉTÉOROLOGIQUE POUR L'ANNÉE

TOTAL DAILY PRECIPITATION OF RAIN & SNOW / PRECIPITATION TOTALE DE PLUIE ET DE NEIGE

DATE	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOÛT	SEPT SEP	OCT OCT	NOV NOV	DEC DEC
1	1.4		TR	2.8						2.2		TR
2		TR	0.4			TR	5.4	15.6		7.2	TR	TR
3	0.2		4.0		TR	8.6	26.8	4.6	0.2	2.4		0.2
4	0.8		0.6		TR	18.1	6.6		2.6	0.2		
5	TR	0.8	1.2			0.8			4.6	2.3		TR
6	3.2		16.4	TR		0.4				0.2		
7	TR		13.6	TR			0.2	14.8		6.3		
8			TR			5.2			0.7	TR		TR
9	4.1	1.6	1.9						7.7		2.5	
10	3.2	2.4		7.3		0.2		38.9	20.5	3.6		1.9
11		2.0								13.7	TR	19.4
12	1.4	TR			TR	TR				7.4		TR
13	2.6		0.2	16.7	0.4			TR	4.3	10.9	2.0	5.5
14	4.6	TR	TR	23.0	TR	1.3				7.8	0.5	TR
15		TR		1.0		3.6			1.6	7.8	TR	1.0
16	2.0	TR	TR	0.2		0.4	5.6		5.4	1.0	TR	0.2
17	TR	0.2	1.6		TR				0.3	0.2	TR	TR
18		4.5	0.2		TR		0.4	TR	TR		TR	TR
19	0.2	9.8			0.9			12.6			10.0	
20		6.9			4.4				0.6		33.9	
21	TR	TR						12.3	0.2		4.2	7.7
22					11.2	2.1			0.4		3.3	1.0
23	TR	TR					0.4				37.5	TR
24	TR				3.4	10.1		0.8		1.0	TR	TR
25	TR											0.8
26				5.0		7.2		0.2		TR	TR	TR
27	TR	5.4	TR				13.4	TR	0.4		TR	
28	TR	0.6		3.4	10.6		0.8	TR	1.4	0.5	7.2	TR
29	12.8				11.1			8.2	17.1		2.6	TR
30	0.4		1.4		5.9	9.9	TR		15.8		TR	
31	0.2		0.6				2.8					
Total	37.1	34.2	42.1	59.4	47.9	67.9	62.4	108.0	83.8	74.7	103.7	37.7

ANNUAL METEOROLOGICAL SUMMARY
SOMMAIRE MÉTÉOROLOGIQUE ANNUEL

for/pour THUNDER BAY "A", ONTARIO YEAR/ANNÉE: 1984

METEOROLOGICAL DATA FOR THE YEAR / DONNÉES MÉTÉOROLOGIQUE POUR L'ANNÉE

TOTAL DAILY PRECIPITATION OF RAIN & SNOW / PRÉCIPITATION TOTALE DE PLUIE ET DE NEIGE

DATE	JAN JAN	FEB FEV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOÛT	SEPT SEP	OCT OCT	NOV NOV	DEC DEC
1	0.2	0.3			TR	8.2			1.0		TR	TR
2		5.6				1.6	4.4		1.2	0.8	TR	2.8
3	0.6	0.8					1.0		0.4		1.2	TR
4	0.2	1.6	0.2			0.4	1.4		1.0	2.6	11.4	TR
5	2.7	0.2	2.6		0.4	11.6	7.8				TR	2.4
6	TR	TR	TR			9.4	1.0	10.2				TR
7	3.5	TR			19.6	2.6		12.6	0.2		TR	TR
8					1.9	7.4	TR	25.8	13.7		3.2	
9	TR					0.8	TR	3.2	3.2			
10			0.2		0.4	26.1			0.2	TR	TR	
11			0.2		0.4	TR	9.6	TR	2.5			
12	0.5	10.4	0.2			8.4	1.1		6.4	TR		
13	2.2	12.3	2.2	TR		6.4	6.6		TR			TR
14	TR	TR	0.8	TR			0.4	TR	1.4		3.4	TR
15	TR		5.2	TR		1.4	1.0	5.3		11.4	0.9	10.3
16	0.3		TR		TR		4.4	TR		2.6	TR	30.8
17		1.2	0.2			0.2	10.2	2.6		16.6		2.6
18						TR						0.6
19	0.2				6.4					28.8	TR	0.2
20			2.7		TR			TR	TR	TR		0.4
21	TR	TR	0.9		12.2			12.2	0.2	0.2		6.5
22	3.6		TR		5.2	0.4	32.9	TR	1.0	TR	0.4	TR
23	TR	TR			TR				0.2			
24	0.2	TR			4.2	TR			8.2	TR		
25		TR		0.6		5.8	7.2	1.2	5.1	2.0		TR
26	1.1			5.8	TR	27.6	0.6		0.6		0.2	5.8
27	2.2	TR		16.4		2.4		13.2		6.4	10.8	0.8
28	3.2			0.6						TR	0.6	6.8
29	TR			0.6	TR			0.2			TR	0.6
30	0.2			2.5	0.6		1.4			3.8	TR	0.4
31	TR				0.4		6.0			7.4		
Total	20.9	32.4	15.4	26.5	51.7	120.7	17	86.5	46.5	82.6	32.1	44

NOTE: TR = less than 0.2

85-179

APPENDIX C

GROUNDWATER CHEMICAL ANALYSES
TBTGS FUEL AREA - 1984

(All values are in mg/L except pH and conductivity
- pH in pH units
- Conductivity in mS/m)

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 01A

TEST	SAMPLING DATE 840517	840518*	840720	840721*
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	340.	--	340.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	340.	390.	340.	330.
B	.090	--	.25	--
CA	87.	--	83.	--
CL	100.	--	98.	--
COND	88.	87.	88.	83.
FE	1.4	--	3.1	--
K	1.9	--	2.1	--
MG	35.	--	40.	--
MN	8.1	--	8.0	--
NA	49.	--	53.	--
NO3	<1.0	--	<1.0	--
PH	7.3	6.5	7.2	6.5
PO4	.080	--	.025	--
SO4	1.6	--	1.3	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 03A

TEST	840517	840518*	840720	840721*
		SAMPLING DATE		
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	520.	--	520.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	520.	570.	520.	520.
B	.060	--	.090	--
CA	130.	--	120.	--
CL	65.	--	64.	--
COND	110.	120.	100.	130.
FE	60.	--	100.	--
K	2.1	--	2.0	--
MG	58.	--	58.	--
MN	1.4	--	1.5	--
NA	44.	--	41.	--
NO3	<1.0	--	3.7	--
PH	7.3	6.6	6.9	6.5
PO4	.10	--	.028	--
SO4	6.0	--	1.7	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 04A

TEST	840517	840518*	840720	840721*
			SAMPLING DATE	
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	460.	--	490.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	460.	540.	490.	580.
B	.080	--	.14	--
CA	110.	--	120.	--
CL	6.7	--	15.	--
COND	84.	98.	97.	120.
FE	87.	--	120.	--
K	5.5	--	6.3	--
MG	47.	--	58.	--
MN	1.0	--	2.0	--
NA	15.	--	13.	--
NO3	<1.0	--	<1.0	--
PH	6.7	6.5	6.8	6.3
PO4	.060	--	.035	--
SO4	21.	--	53.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 05C

SAMPLING DATE

TEST	840517	840518*	840720	840721 *
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	940.	--	1000.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	940.	1100.	1000.	1000.
B	.10	--	.12	--
CA	310.	--	310.	--
CL	180.	--	130.	--
COND	200.	220.	210.	230.
FE	94.	--	110.	--
K	3.7	--	3.8	--
MG	97.	--	100.	--
MN	3.7	--	3.4	--
NA	43.	--	41.	--
NO3	<1.0	--	<1.0	--
PH	7.0	6.6	7.1	6.8
PO4	.070	--	.036	--
SO4	66.	--	92.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 06B

TEST	840517	840518*	840720	840721*
			SAMPLING DATE	
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	570.	--	550.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	570.	620.	550.	550.
B	.070	--	.080	--
CA	230.	--	220.	--
CL	400.	--	320.	--
COND	180.	210.	190.	190.
FE	25.	--	12.	--
K	3.4	--	3.2	--
MG	72.	--	75.	--
MN	2.6	--	2.4	--
NA	55.	--	53.	--
NO3	<1.0	--	<1.0	--
PH	7.9	6.8	7.3	6.8
PO4	.090	--	.025	--
SO4	<1.0	--	1.2	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 06C

SAMPLING DATE

TEST	840517	840518*	840720	840721*
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	750.	--	780.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	750.	900.	780.	850.
B	.090	--	.19	--
CA	310.	--	330.	--
CL	100.	--	120.	--
COND	200.	210.	240.	250.
FE	120.	--	160.	--
K	3.3	--	3.0	--
MG	100.	--	120.	--
MN	3.0	--	3.4	--
NA	41.	--	52.	--
NO3	<1.0	--	<1.0	--
PH	6.6	6.5	6.9	6.6
PO4	.10	--	.026	--
SO4	410.	--	520.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 07B

TEST	840517	840518*	840720	840721*
		SAMPLING DATE		
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	<5.0	--	380.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	390.	430.	380.	360.
B	.19	--	.24	--
CA	120.	--	110.	--
CL	93.	--	58.	--
COND	91.	94.	82.	83.
FE	13.	--	9.6	--
K	1.7	--	1.5	--
MG	40.	--	39.	--
MN	1.7	--	1.7	--
NA	21.	--	16.	--
NO3	<1.0	--	<1.0	--
PH	7.7	6.9	7.2	6.9
PO4	.090	--	.032	--
SO4	<1.0	--	5.8	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 08B

TEST	840517	840518*	840720	840721*
		SAMPLING DATE		
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	110.	--	13.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	110.	160.	13.	70.
B	.71	--	.90	--
CA	35.	--	110.	--
CL	11.	--	9.5	--
COND	29.	29.	76.	30.
FE	1.7	--	130.	--
K	2.4	--	2.8	--
MG	4.2	--	43.	--
MN	.37	--	21.	--
NA	22.	--	35.	--
NO3	<1.0	--	1.7	--
PH	7.7	6.9	5.9	6.8
PO4	.080	--	<.015	--
SO4	21.	--	370.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 12C

TEST	840517	840518*	840720	840721*
		SAMPLING DATE		
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	15.	--	32.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	15.	80.	32.	40.
B	1.2	--	1.8	--
CA	200.	--	260.	--
CL	18.	--	14.	--
COND	150.	140.	180.	170.
FE	17.	--	9.6	--
K	5.0	--	7.2	--
MG	61.	--	76.	--
MN	37.	--	38.	--
NA	35.	--	40.	--
NO3	<1.0	--	<1.0	--
PH	6.0	5.9	6.2	5.5
PO4	.050	--	<.015	--
SO4	1100.	--	1000.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 13B

TEST	840517	840518*	840720	840721*
		SAMPLING DATE		
ACID8.3	760.	--	1200.	--
ALKCO3	--	--	<5.0	--
ALKHCO3	--	--	<5.0	--
ALKOH	--	--	<5.0	--
ALKTOT	--	100.	<5.0	130.
B	4.2	--	3.6	--
CA	490.	--	460.	--
CL	22.	--	24.	--
COND	470.	440.	440.	440.
FE	750.	--	830.	--
K	10.	--	11.	--
MG	210.	--	230.	--
MN	120.	--	110.	--
NA	110.	--	110.	--
NO3	<1.0	--	<1.0	--
PH	4.1	5.8	5.1	6.0
PO4	.13	--	.073	--
SO4	4100.	--	4200.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 13C

TEST	840517	840518*	840720	840721*
			SAMPLING DATE	
ACID8.3	780.	--	920.	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	<5.0	--	<5.0	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	<5.0	180.	<5.0	150.
B	3.4	--	3.6	--
CA	490.	--	520.	--
CL	27.	--	27.	--
COND	440.	490.	460.	470.
FE	670.	--	840.	--
K	7.9	--	8.0	--
MG	210.	--	240.	--
MN	120.	--	120.	--
NA	99.	--	110.	--
NO3	<1.0	--	<1.0	--
PH	4.6	6.0	5.5	6.0
PO4	.11	--	.070	--
SO4	3900.	--	3700.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 14A

TEST	840517	840518 *	840720	840721 *
			SAMPLING DATE	
ACID8.3	780.	--	920.	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	<5.0	--	<5.0	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	<5.0	200.	<5.0	90.
B	1.4	--	1.6	--
CA	450.	--	390.	--
CL	60.	--	59.	--
COND	440.	450.	440.	440.
FE	61.	--	700.	--
K	4.1	--	4.5	--
MG	220.	--	270.	--
MN	90.	--	86.	--
NA	180.	--	180.	--
NO3	<1.0	--	12.	--
PH	4.8	6.1	5.3	6.1
PO4	.11	--	.055	--
SO4	3600.	--	3200.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 14B

TEST	SAMPLING DATE 840517	840518*	840720	840721*
ACID8.3	360.	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	<5.0	--	10.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	<5.0	140.	10.	80.
B	1.4	--	1.6	--
CA	350.	--	380.	--
CL	15.	--	19.	--
COND	320.	360.	380.	370.
FE	220.	--	330.	--
K	5.8	--	7.4	--
MG	150.	--	180.	--
MN	69.	--	71.	--
NA	210.	--	110.	--
NO3	<1.0	--	<1.0	--
PH	4.7	6.1	5.9	5.9
PO4	.080	--	.040	--
SO4	2400.	--	2500.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 14C

TEST	840517	840518*	840720	840721*
		SAMPLING DATE		
ACID8.3	30.	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	<5.0	--	35.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	<5.0	160.	35.	85.
B	.95	--	1.2	--
CA	190.	--	230.	--
CL	8.0	--	8.1	--
COND	200.	230.	240.	230.
FE	39.	--	81.	--
K	3.0	--	3.6	--
MG	70.	--	83.	--
MN	26.	--	32.	--
NA	190.	--	190.	--
NO3	<1.0	--	3.4	--
PH	6.7	6.4	6.2	6.3
PO4	.030	--	<.015	--
SO4	1200.	--	1400.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 15A

SAMPLING DATE

TEST	840517	840518*	840720	840721*
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	750.	--	770.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	750.	960.	770.	880.
B	.11	--	.15	--
CA	190.	--	210.	--
CL	160.	--	120.	--
COND	160.	190.	170.	180.
FE	100.	--	89.	--
K	1.9	--	2.1	--
MG	88.	--	87.	--
MN	4.2	--	3.5	--
NA	27.	--	27.	--
NO3	<1.0	--	<1.0	--
PH	6.8	6.6	6.8	6.8
PO4	.060	--	.030	--
SO4	8.0	--	1.7	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 15B

TEST	840517	840518*	840720	840721*
		SAMPLING DATE		
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	840.	--	920.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	840.	920.	920.	940.
B	.070	--	.16	--
CA	200.	--	230.	--
CL	7.6	--	10.	--
COND	160.	180.	160.	160.
FE	1.6	--	26.	--
K	7.9	--	7.6	--
MG	95.	--	90.	--
MN	10.	--	11.	--
NA	16.	--	13.	--
NO3	<1.0	--	<1.0	--
PH	7.3	6.3	7.4	6.6
PO4	.060	--	<.015	--
SO4	150.	--	88.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 16A

TEST	840517	840518*	840720	840721*
	SAMPLING DATE			
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	760.	--	690.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	760.	1700.	690.	680.
B	.16	--	.20	--
CA	210.	--	200.	--
CL	150.	--	140.	--
COND	160.	190.	160.	180.
FE	86.	--	110.	--
K	2.6	--	2.6	--
MG	89.	--	83.	--
MN	2.9	--	2.4	--
NA	30.	--	23.	--
NO3	<1.0	--	<1.0	--
PH	6.8	6.5	6.8	6.6
PO4	.080	--	.034	--
SO4	16.	--	7.3	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 16B

TEST	840517	840518 *	840720	840721 *
	SAMPLING DATE			
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	710.	--	690.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	710.	850.	690.	900.
B	.21	--	.16	--
CA	140.	--	110.	--
CL	35.	--	43.	--
COND	140.	180.	130.	150.
FE	110.	--	120.	--
K	6.6	--	6.9	--
MG	75.	--	68.	--
MN	1.8	--	1.6	--
NA	96.	--	71.	--
NO3	<1.0	--	<1.0	--
PH	6.8	6.4	6.6	6.5
PO4	.060	--	.030	--
SO4	150.	--	25.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 17A

TEST	840517	840518*	840720	840721*
		SAMPLING DATE		
ACID8.3	--	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	690.	--	660.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	690.	860.	660.	620.
B	.16	--	.24	--
CA	290.	--	230.	--
CL	80.	--	84.	--
COND	240.	260.	210.	240.
FE	160.	--	180.	--
K	7.6	--	9.1	--
MG	120.	--	100.	--
MN	3.8	--	3.2	--
NA	120.	--	94.	--
NO3	<1.0	--	<1.0	--
PH	6.5	6.3	6.8	6.3
PO4	.060	--	.034	--
SO4	1000.	--	470.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 17B

TEST	840517	840518 *	840720	840721 *
		SAMPLING DATE		
ACID8.3	--	--	--	--
ALKCO3	--	--	<5.0	--
ALKHCO3	--	--	800.	--
ALKOH	--	--	<5.0	--
ALKTOT	--	--	800.	850.
B	--	--	.22	--
CA	91.	--	190.	--
CL	--	--	46.	--
COND	--	220.	160.	150.
FE	9.0	--	21.	--
K	16.	--	6.6	--
MG	42.	--	98.	--
MN	2.0	--	5.2	--
NA	240.	--	37.	--
NO3	--	--	<1.0	--
PH	--	6.5	7.0	6.8
PO4	--	--	.026	--
SO4	--	--	100.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 18A

TEST	840517	840518*	840720	840721 *
		SAMPLING DATE		
ACID8.3	640.	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	<5.0	--	9.2	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	<5.0	180.	9.2	160.
B	2.8	--	3.3	--
CA	470.	--	460.	--
CL	30.	--	30.	--
COND	390.	430.	420.	410.
FE	500.	--	630.	--
K	7.4	--	9.0	--
MG	180.	--	210.	--
MN	94.	--	110.	--
NA	120.	--	130.	--
NO3	<1.0	--	11.	--
PH	4.5	6.2	5.8	6.2
PO4	.10	--	.064	--
SO4	3200.	--	3000.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 18B

TEST	840517	840518 *	840720	840721 *
	SAMPLING DATE			
ACID8.3	180.	--	--	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	12.	--	16.	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	12.	100.	16.	110.
B	1.7	--	1.9	--
CA	210.	--	220.	--
CL	14.	--	16.	--
COND	200.	190.	230.	230.
FE	70.	--	170.	--
K	5.4	--	6.6	--
MG	92.	--	99.	--
MN	51.	--	51.	--
NA	98.	--	95.	--
NO3	<1.0	--	<1.0	--
PH	5.6	6.1	5.9	6.1
PO4	.070	--	.027	--
SO4	1300.	--	1400.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 19A

TEST	840517	840518 *	840720	840721 *
		SAMPLING DATE		
ACID8.3	720.	--	770.	--
ALKCO3	<5.0	--	<5.0	--
ALKHCO3	<5.0	--	5.0	--
ALKOH	<5.0	--	<5.0	--
ALKTOT	<5.0	220.	5.0	100.
B	1.5	--	1.6	--
CA	410.	--	350.	--
CL	43.	--	42.	--
COND	410.	380.	410.	400.
FE	510.	--	550.	--
K	4.5	--	4.8	--
MG	200.	--	210.	--
MN	76.	--	74.	--
NA	210.	--	200.	--
NO3	<1.0	--	<1.0	--
PH	4.7	6.0	5.4	6.0
PO4	.11	--	.054	--
SO4	3200.	--	2900.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

FUEL STORAGE AREA GROUNDWATER QUALITY-TBTGS-1984

LOCATION : 19B

TEST	840517	840518*	840720	840721*
			SAMPLING DATE	
ACID8.3	--	--	590.	--
ALKCO3	--	--	<5.0	--
ALKHCO3	--	--	<5.0	--
ALKOH	--	--	<5.0	--
ALKTOT	--	--	<5.0	10.
B	--	--	1.9	--
CA	430.	--	380.	--
CL	--	--	18.	--
COND	--	370.	400.	360.
FE	260.	--	360.	--
K	11.	--	12.	--
MG	190.	--	210.	--
MN	90.	--	89.	--
NA	190.	--	200.	--
NO3	--	--	<1.0	--
PH	--	4.8	5.1	4.6
PO4	--	--	.060	--
SO4	--	--	2700.	--

* TBTGS data obtained on fresh samples taken on the day before that shown.

APPENDIX D

STATISTICAL REPORT

by

Dr. S.A. Bartlett

91602
new 82-10

ontario hydro
research division

To: Mr. F.J. Kee
Director of Research

STATISTICAL ANALYSIS OF TBTGS COAL STORAGE AREA GROUNDWATER

S.A. Bartlett

ABSTRACT

The Ministry of the Environment required that the groundwater area surrounding two coal storage piles at Thunder Bay TGS be monitored for possible leachate formation. To fulfill this directive, Ontario Hydro implemented a program to collect water samples which were analyzed for concentration levels of a number of ionic species. At the request of the Chemical Research Department, a statistical analysis of the data was performed. Analysis of variance was done for each chemical test to evaluate the effects of location of groundwater sampling, depth of sampling, date of sampling, and of which laboratory did the chemical analysis on concentration levels. All factors except depth were found to be statistically significant in the majority of tests. Depth was significant for only some tests.

1. INTRODUCTION

The Thunder Bay TGS (TBTGS) on Mission Island at Thunder Bay has two coal storage piles, one of lignite coal and the other of bituminous coal. The Ministry of the Environment required that the groundwater in the area surrounding the piles be monitored for possible leachate formation from the coal piles. In 1979,

job	file	date	report no.
740631-531-861	809.710	September 9, 1985	85-232-K

Ontario Hydro implemented a program for the systematic collection and analysis of groundwater samples to fulfill this directive.

To monitor the groundwater, water samples were collected several times a year from wells placed around the coal piles. Chemical analyses of the samples were carried out by three laboratories. Concentration levels of several ionic species for each sample were measured. If any concentration levels are found to be higher than normal or to be consistently increasing in time, then leachate formation may be suspected. It is, of course, necessary to define the "normal" levels of concentration.

The first step taken towards establishing normal bounds on the ionic concentration levels consisted of studying the factors that significantly influenced those levels. As explained later in this report, potential factors included date of sampling, location of the sampling site, depth of sampling, and the laboratory where testing was carried out. The objective of the statistical analysis was to carry out this first step.

This report summarizes the results of the statistical analysis. The approach was similar to that used for the flyash data analysis/1/.

2. THE DATA

Groundwater samples were collected from a number of piezometers (observation wells) which were installed in two stages near the coal piles. In 1979, London Monenco Consultants Ltd (LMC) installed piezometers at 14 locations, each having piezometers at 3 depths except at location numbers 1, 3 and 11 which had piezometers at 2 depths. In 1980, Ontario Hydro installed piezometers at 6 more locations, numbered 15 through 20, with piezometers at 2 depths.

All piezometers were installed in the same geological stratum comprised of silty sand. However, the depth values separating the deep, medium, and shallow levels were inconsistent. For example, the shallow level of piezometer site 5 was at the same depth (approximately) as the medium level of piezometer site 7. This inconsistency may affect the analysis.

Not all laboratories analyzed samples from all piezometer locations. In 1979, analyses were performed by LMC. Since only location numbers 1 through 14 were in operation in 1979, the laboratory at LMC performed analyses on samples collected exclusively from those 14 locations. From 1980 to 1984, analyses were carried out by the laboratories at the TBTGS and the Research Division. Each performed analyses on samples collected from all 20 locations. Table I lists the sampling dates for

which each testing location was responsible.

Each groundwater sample was analyzed for concentration levels of 40 ionic species and 3 measures of acidity (pH, ACID4.5 and ACID8.3), or a subset thereof. The LMC and Research Division laboratories performed all the chemical analyses, whereas the TBTGS laboratory performed a subset of representative analyses. A chemical analysis will be called a test in this report to distinguish it from a statistical analysis.

The instrument used for measuring concentration levels contributed two additional sources of error. Not only was it calibrated each day a test was performed, but concentrations below a certain level were impossible to detect (referred to as being below detection limit). Detection limits depend on the calibration and thus may change from day to day. Concentration levels below detection limit are treated as missing data.

Summary statistics, such as means, standard deviations, maxima and minima for the values of each test, excluding data below detection limit, are given in Table II. The number of observations above and below detection limit for each test are also included in the table. Many of the tests had a high number of concentration levels below detection limit (see Table II) resulting in the rejection of 34% of the observations. For some tests, almost all the data were rejected while, for others, none were rejected.

3. STATISTICAL ANALYSIS AND RESULTS

3.1 Methodology

The statistical procedure called analysis of variance was used to investigate those factors which may influence the values of the chemical tests, each test being treated separately. These factors were as follows:

- the laboratory where groundwater samples were tested (henceforth referred to as the Lab factor);
- the date on which groundwater samples were gathered (Date factor);
- location of piezometers (Site factor);
- depth of piezometer (Depth factor).

In addition to the above factors, the interaction between the Site and Depth factors was also included in the statistical analysis. The other interactions were assumed to have negligible

impact on the concentration levels and were thus ignored.

When analysis of variance is carried out, the usual assumptions made about the data are that the observations are normally distributed with the same variance and are independent of each other. The plausibility of these assumptions was investigated on concentration levels in flyash data/1/. It was concluded that applying a natural logarithm (ln) transformation to the data was required to ensure the validity of the analysis. Therefore, this transformation was used in the coal storage data analysis.

The analysis of the main factors and the interaction between the Site and Depth factors will be referred to as the "complete" analysis. Of the 43 chemical tests, there were 10 tests which did not have enough observations above detection limit to justify a "complete" analysis. They were $ALKCO_3$, ALKTOT, Be, Br, I, Mo, Pb, Se, Sn, and Ti. Computing was carried out using the General Linear Models (GLM) procedure of the Statistical Analysis System (SAS) computer software package.

A factor was considered to be significant if the hypothesis that different levels of the factor produce identical test results could be rejected at the 0.05 level of significance. A hypothesis is rejected at this level of significance if it can be shown that it is not valid at least 95% of the time.

3.2 Results

The results are summarized in Table III. The Lab factor was significant for 21 out of 33 tests (64%). Only 11 tests involved the comparison of all 3 laboratories (the TBTGS laboratory carried out a subset of the 43 tests). Of those 11 tests, 9 had a significant Lab factor. Moreover, of those 9 tests, all 3 laboratories were significantly different from each other. The remaining tests involved the comparison of 2 laboratories except for one test (ACID8.3) which was only done by the Research Division laboratory.

High percentages of the tests had a significant Date factor (26 out of 33 tests, 79%). This was expected because of the inherent monthly variation in concentration levels.

The Site factor was significant for 27 out of 33 tests (82%). Geological differences and proximity to the different coal piles could have contributed to the variation between sites.

Less than half the tests (14 out of 33 or 45%) yielded significant interaction between the Site and Depth factors. In addition to weak evidence supporting the presence of significant interaction, an even smaller percentage of tests

yielded a significant Depth factor (6 out of 33 or 18%). The lack of conformity in these conclusions could have resulted from the inconsistent depth values.

The significance of the Depth factor and the interaction between Depth and Site factors was also examined using R-square (the coefficient of determination) values. R-square is a measure of the proportion of the total variation between observations explained (described) by all factors included in an analysis of variance. A value of 1 implies that all variation has been explained, while a value of 0 implies that none of the variation has been explained.

For each test, the R-square statistic was computed for the "complete" analysis, then recomputed for the analysis omitting the Depth factor and interaction between Site and Depth. For the "complete" analysis, 26 out of 33 tests (79%) had R-square of 0.70 or more. For the subsequent analysis, 22 out of 33 (67%) had R-square of 0.70 or more. The R-square values are also given in Table III.

From the above discussion, it was concluded that the Depth factor and the interaction between the Depth and Site factors could be removed without dramatically reducing the variation explained by the "complete" analysis. Eliminating the interaction enables more detailed inference to be made about site since it is no longer linked with depth. Consequently, an analysis of site was executed which attempted to model ln(concentration) as a continuous change from piezometer site to piezometer site.

The piezometer locations were renumbered so that their numbers were adjacent to each other and progressed sequentially around the coal storage piles. The new numbers 1 to 12 corresponded to piezometer sites nearest to the lignite coal pile while the new numbers 13 to 20 corresponded to piezometer sites nearest to the bituminous coal pile. The reordering is given below.

PIEZOMETER LOCATION NUMBERS

Old	New	Old	New	Old	New
1	1	5	8	9	15
2	2	6	9	12	16
11	3	17	10	18	17
3	4	7	11	13	18
4	5	20	12	14	19
15	6	8	13	19	20
16	7	10	14		

The piezometer site variation was modeled to see if ln(concentration) varied cubically with Site number. A cubic relation was chosen after inspecting plots of ln(concentration) versus Site number. It was clear that a cubic equation was sufficient to describe the relationship. For many of the tests, the R-square value dropped notably (see Table IV). If R-square drops too much, then not enough variation is explained by the model. However, there were a few cases where modeling seemed appropriate. They were $ALKHCO_3$, ALKTOT, B, Cr, and PO_4. Each had R-squares of 0.75 or greater. Other tests with pronounced trends but lower R-squares were pH (0.42), SO_4 (0.67), and Mn (0.65). $ALKHCO_3$, ALKTOT, and pH had decreasing cubic trends as the piezometer site numbers progressed from the lignite to bituminous coal piles, while B, Cr, PO_4, Mn, and SO_4 had increasing cubic trends. Figure 1 shows an example of the trend for species $ALKHCO_3$.

The Date variation was not modeled in greater detail. The mean ln (concentration) for each month and year combination were computed and plotted as trends over 12 months for each year. These plots showed widely fluctuating means that appeared to be random. It was difficult to state that yearly means were increasing or decreasing with time. Figure 2 shows an example for species $ALKHCO_3$.

4. SUMMARY

The results of the statistical analysis of the coal storage data are summarized below.

- Lab was significant for the majority (64%) of chemical tests.
- Depth (of piezometer) was significant in only 18% of the tests though the interaction between Depth and Site was significant for almost half (45%) of the tests. Eliminating these effects did not dramatically decrease the variation explained by the analysis as measured by R-square.
- Site was significant for the majority (82%) of chemical tests. Further analysis showed that some species had higher values near the bituminous coal pile than by the lignite coal pile, while others had lower values.
- Date was significant for 79% of the tests.

5. RECOMMENDATIONS FOR FUTURE TESTING

It is recommended that the following points be considered when planning a similar evaluation.

- If month-to-month variation is of interest, groundwater samples should be collected every one or two months. This may not be possible in the winter months when the ground is frozen.

- If year-to-year variation is of interest, then groundwater samples only need to be collected once or twice a year provided that sampling is done at the same time each year. This will make the yearly data comparable by eliminating monthly variation.

- If the number of piezometer sites from which samples are collected is reduced, then representative sites from the bituminous and lignite coal piles should remain in operation.

Approved:

J. G. Cassan
Manager
Operations Research Dept

Submitted:

S. A. Bartlett
Mathematician
Reliability and Statistics Section
Operations Research Dept

SAB:cmh

REFERENCES

1. Bartlett, S.A., "Groundwater Data Analysis: Sources of Variation". Report N85-1-K, May 8, 1985.

TABLE I

SAMPLING DATES GROUPED BY
LABORATORY RESPONSIBLE FOR ANALYSIS

London Monenco Ltd. (LMC)	Research Division	Thunder Bay TGS (TBTGS)
79-06-14	80-07-04	80-06-24
79-09-27	81-05-11	80-09-19
	82-05-18	81-08-26
	82-08-25	82-05-19
	82-11-18	82-08-26
	83-06-02	82-11-19
	83-07-26	83-06-03
	83-09-21	83-07-27
	84-05-17	83-09-22
	84-07-20	84-05-18
		84-07-21

Note: Notation for the date is yy-mm-dd where yy is year, mm is month, and dd is day.

TABLE II
FUEL STORAGE DATA SET
SUMMARY STATISTICS
EXCLUDING DETECTION LIMITS

OBS	CHEMICAL SPECIES	NO. OF OBS. ABOVE DETECTION LIMIT	NO. OF OBS. BELOW DETECTION LIMIT	MEAN *	STANDARD DEVIATION *	MAXIMUM *	MINIMUM *
1	ACID4.5	54	0	231.23704	550.15495	2900.00000	3.20000
2	ACID8.3	39	0	673.74359	672.57470	3300.00000	23.00000
3	AG	21	78	0.00120	0.00205	0.00700	0.00020
4	AL	38	61	2.13342	4.84695	21.10000	0.09000
5	ALKCO3	4	137	26.50000	18.19341	44.00000	1.00000
6	ALKHCO3	320	21	415.98656	330.87473	1230.00000	4.00000
7	ALKOH	0	144	.	.	.	.
8	ALKTOT	180	10	418.95111	338.83264	1730.00000	4.00000
9	AS	60	38	0.01039	0.01057	0.05000	0.00100
10	B	204	64	1.50893	2.05968	19.80000	0.04000
11	BA	74	26	0.21008	0.16784	0.90600	0.01000
12	BE	11	88	0.01052	0.01795	0.05400	0.00010
13	BR	17	5	0.77412	0.77533	3.00000	0.10000
14	CA	315	0	194.94444	120.64620	590.00000	13.00000
15	CD	44	55	0.08068	0.13329	0.40000	0.00010
16	CL	337	0	95.24866	137.22776	1045.00000	6.70000
17	CO	64	58	0.22705	0.43223	2.20000	0.00080
18	COND	528	0	231.24564	165.04874	2030.00000	23.00000
19	CR	78	43	0.03738	0.05144	0.20000	0.00100
20	CU	61	38	0.01577	0.02524	0.11400	0.00100
21	F	60	26	0.95417	1.31855	5.30000	0.10000
22	FE	312	3	128.27317	176.71037	916.00000	0.05000
23	HG	59	40	0.00048	0.00070	0.00320	0.00001
24	I	6	16	0.15667	0.08501	0.30000	0.08000
25	K	258	8	5.92845	4.41393	33.00000	1.00000
26	MG	292	0	95.40377	120.27098	1460.00000	1.70000
27	MN	313	0	24.37617	36.98839	195.00000	0.25000
28	MO	13	86	0.51154	0.16522	0.79000	0.20000
29	NA	315	0	111.93460	243.98083	3963.00000	7.40000
30	NI	47	52	0.25860	0.42477	1.58000	0.00350
31	NO3	48	108	3.61437	6.72213	25.00000	0.02000
32	PB	11	88	0.01809	0.02496	0.06000	0.00200
33	PH	528	0	6.36301	1.01855	8.50000	1.37000
34	PO4	146	189	0.98186	3.11523	25.00000	0.01200
35	SE	3	95	0.00333	0.00700	0.00700	0.00100
36	SI	121	0	21.64231	6.52338	38.40000	3.90000
37	SN	8	22	0.00512	0.00196	0.00800	0.00200
38	SO4	314	22	933.10217	1223.60928	4440.00000	0.30000
39	SR	97	2	0.68562	0.77381	5.48000	0.13000
40	TH	12	88	0.08047	0.17263	0.62000	0.00020
41	TI	6	93	0.60517	0.68745	1.60000	0.00800
42	V	50	49	0.01470	0.01385	0.06000	0.00100
43	ZN	60	39	0.30483	0.47163	2.30000	0.02000

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* All concentrations are mg/L except pH (unitless) and COND (mS/m).

NOTE: "." denotes missing value.

TABLE III

STATISTICAL SIGNIFICANCE RESULTS FOR EACH CHEMICAL TEST

Test	Site	Depth	Site x Depth	Lab	Date	Rsq[1]	Rsq[2]
ACID4.5	*	ns	ns	ns	*	0.81	0.75
ACID8.3	*	*	*	-	*	0.92	0.62
AG	ns	ns	ns	*	*	0.94	0.89
AL	ns	ns	ns	ns	ns	0.62	0.52
ALKHCO3	*	*	ns	ns	*	0.85	0.83
ALKTOT	*	ns	ns	ns	*	0.85	0.85
AS	*	ns	ns	ns	*	0.69	0.55
B	*	ns	*	*	*	0.86	0.84
BA	*	ns	ns	ns	*	0.89	0.86
CA	*	ns	*	*	*	0.71	0.68
CD	ns	ns	ns	*	*	0.96	0.93
CL	*	ns	*	*	*	0.77	0.70
CO	*	ns	ns	*	*	0.91	0.89
COND	*	ns	*	*	*	0.80	0.77
CR	*	*	*	*	*	0.94	0.92
CU	*	ns	ns	*	ns	0.73	0.65
F	*	*	ns	ns	ns	0.80	0.73
FE	*	ns	*	*	*	0.66	0.62
HG	ns	ns	ns	*	*	0.74	0.67
K	*	ns	*	*	*	0.64	0.58
MG	*	ns	*	ns	*	0.74	0.66
MN	*	*	*	ns	*	0.83	0.80
NA	*	ns	*	*	*	0.75	0.73
NI	*	ns	ns	*	ns	0.88	0.82
NO3	*	ns	ns	ns	*	0.85	0.84
PH	*	ns	ns	*	*	0.51	0.49
PO4	*	ns	ns	*	*	0.90	0.88
SI	*	*	*	*	*	0.71	0.54
SO4	*	ns	*	*	*	0.79	0.76
SR	*	ns	*	*	*	0.76	0.64
TH	ns	ns	-	ns	ns	0.99	0.99
V	ns	ns	ns	*	ns	0.71	0.62
ZN	*	ns	ns	*	ns	0.79	0.75
No of *	27	6	14	21	26		
No of ns	6	27	18	11	7		
No of -	0	0	1	1	0		
total	33	33	33	33	33		

Legend: * significant with $p < 0.05$
ns not significant

Note: Species with 16 or less observations above detection [illegible]

TABLE IV

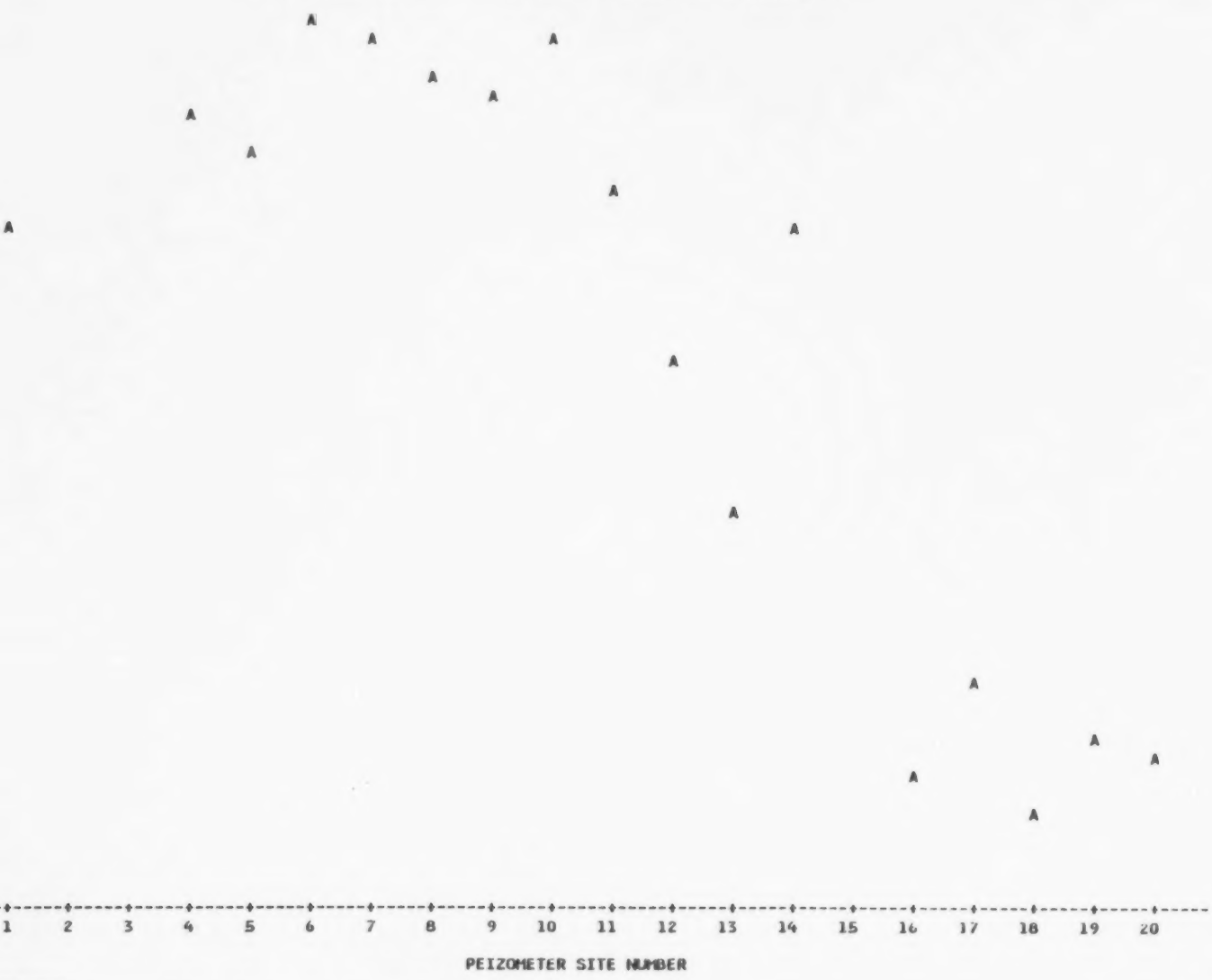
RESULTS OF CUBIC MODELING OF PIEZOMETER SITE NUMBERS

Test	Linear	Quadratic	Cubic	R-square
ACID4.5	*	ns	ns	0.59
ACID8.3	*	ns	*	0.60
AG	ns	ns	ns	0.89
AL	*	ns	ns	0.33
ALKHCO3	*	*	*	0.78
ALKTOT	*	*	*	0.78
AS	ns	*	ns	0.33
B	*	ns	*	0.73
BA	*	*	ns	0.61
CA	*	ns	*	0.50
CD	*	ns	ns	0.90
CL	*	*	*	0.41
CO	*	ns	*	0.75
COND	*	*	*	0.52
CR	*	*	ns	0.90
CU	ns	ns	ns	0.34
F	*	ns	ns	0.50
FE	*	ns	*	0.48
HG	ns	ns	ns	0.43
K	*	ns	ns	0.25
MG	*	*	*	0.41
MN	*	*	ns	0.65
NA	*	*	*	0.54
NI	*	ns	ns	0.44
NO3	*	ns	ns	0.67
PH	*	*	ns	0.42
PO4	*	*	ns	0.88
SI	*	ns	ns	0.30
SO4	*	*	ns	0.67
SR	*	*	*	0.43
TH	ns	ns	ns	0.99
V	*	*	ns	0.48
ZN	ns	ns	ns	0.19

Legend: * significant with $p < 0.05$
ns not significant

Note: Species with 16 or less observations above detection limit

FIGURE 1
PLOT OF AVERAGE LN CONCENTRATION LEVEL
VS. PIEZOMETER SITE NUMBER
TEST=ALKHCO3



Note: Concentration level is in mg/L

FIGURE 2

PLOT OF AVERAGE LN CONCENTRATION LEVEL
VS. YEAR
TEST = ALKHCO3